Comparison of Well Testing and Production Data Analysis for Estimating Reservoir Parameters

By

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Dissertation submitted in partial fulfilment of
the requirements for the

Degree of Study (Hons)
(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

TEO CHUN TAT

ABSTRACT

This project studies on the applicability of the Pressure Transient Analysis (PTA) and Rate Transient Analysis (RTA) in estimating reservoir parameters. Reservoir parameters refer to the characteristics of the reservoir to store hydrocarbons and produce them, such as permeability and skin factor. Both PTA and RTA are independent of each other as PTA make use of Pressure-Time data and RTA make use of Rate-Time data in their analysis. However, the derivation of the equations for both PTA and RTA are actually based on the application of diffusivity equation. In this project, both PTA and RTA are applied to analyze the pressure-time data and flow rate-time data obtained from the same well. The results yield by these two methods are then compared and analyzed. It is found that these two methods yield reasonably closed estimation of the reservoir parameters of the same well.

Acknowledgement

First and foremost, I would like to thank the Petroleum Engineering Department of Universiti Teknologi PETRONAS (UTP) for providing such an interactive learning platform for me to complete my Final Year Project (FYP).

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NOMENCLATURES AND ABBREVIATIONS

A	:	Drainage Area
CTP	:	Constant Terminal Pressure
CTR	:	Constant Terminal Rate
ETR	:	Early Time Region
IARF	:	Infinite Acting Radial Flow
IFO	:	Injection Fall-Off
LTR	:	Late Time Region
MDH	:	Miller-Dyes-Hutchinson
MTR	:	Middle Time Region
PBU	:	Pressure Buildup
PDD	:	Pressure Drawdown
PTA	:	Pressure Transient Analysis
RDE	:	Radial Diffusivity Equation
RTA	:	Rate Transient Analysis
STB	:	Stock Tank Barrel
STB/D	:	Stock Tank Barrel per Day
Saphir	:	Name of the Software for Pressure Transient Analysis
Topaze	:	Name of the Software for Rate Transient Analysis
Well A	:	Name of the Well in Study
B_o	:	Oil Formation Volume Factor, bbl/STB
C_{sD}	:	Dimensionless Wellbore Coefficient
h	:	Pay Zone Thickness, ft
k	:	Permeability, milli darcy
m	:	Slope of the Middle Time Region

ø	:	Porosity
p	:	Pressure
p_D	:	Dimensionless Pressure
p_i	:	Initial Reservoir Pressure, psia
p_{ws}	:	Bottom-hole Pressure, psia
Q	:	Flow Rate
q_D	:	Dimensionless Flow Rate
r_e	:	Reservoir Radius, ft
r_w	:	Wellbore Radius, ft
s	:	Skin Factor
t	:	Time, hours
t_p	:	Producing Time, hours
t_D	:	Dimensionless Time

CHAPTER 1: INTRODUCTION

1.1 Background

Diffusivity Equation is the most basic mathematical equation used in the oil and gas industry to illustrate the complex phenomenon of fluid flow through porous media. This equation can be developed by combining the equation of conservation of mass with equation of motion and equation of state. The diffusivity equation can be derived for any geometry, but when it comes to flow around the wellbore, the radial flow geometry is the most interest of petroleum engineer. The radial form of diffusivity equation, also known as radial diffusivity equation (RDE) is shown as Equation 1 in Appendix A.

In principle, this RDE can be solved by two main approaches, known as the constant terminal rate solution (CTR) and the constant terminal pressure solution (CTP). Each of these approaches has its own set of initial and boundary conditions imposed.

Pressure transient analysis (PTA), which is also commonly known as well testing, is a routine method reservoir engineers use for reservoir evaluation and characterization. All of the equations used in well testing are derived from the CTR solution of the RDE with different boundary conditions. There are a number of well testing methods, such as Pressure Buildup (PBU), Pressure Drawdown (PDD), and Injection Fall-Off (IFO) etc. All of these methods are based on the same principle: manipulating the production rate of the well and recording the pressure versus time data. The data collected can then be interpreted using various techniques such as Type Curve matching, Horner, MDH etc. The purpose of well testing is to determine the permeability (k), skin (s), drainage area (A), distance to boundary/fault of the reservoir etc. Reliable results can be obtained if the data collected are of good quality and the analysis are properly done.

Decline curve analysis, on the other hand takes on the opposite approach to well testing. Decline curve analysis involved the analysis of flow rate versus time data over a long period of time. Arp's, or conventional decline curve analysis was formulated from empirical observation. In this technique, past production data is plotted on a graph paper against time. A best fit straight line will be drawn through the data and be used to predict future performances of the well. The ultimate goal of the conventional decline curve analysis is to forecast future oil rate, recovery factor and estimated ultimate recovery of the well.

Advanced Decline Curve Analysis is an improvement of conventional decline curve analysis. Originally proposed by Fetkovich, latter improved by other researchers (Blasingame, Agarwal etc.), the advanced decline curve analysis involves the use of type curves. These type curves are composite of analytical and empirical models and are capable of producing a unique solution to estimate reservoir properties, such as permeability (k), skin (s), drainage area (A) etc. These techniques are also called Production Data Analysis (RTA) or Rate Transient Analysis (RTA).

This project aims to apply both of the PTA and RTA on a few sets of well test data and production data. The resulting well parameters from both of these methods will then be compared and investigated.

1.2 Problem Statement

Estimating reservoir characteristics and properties has long been a challenge in the petroleum industry. Traditionally, PTA or pressure surveillance has been widely used by oil and gas companies in estimating the reservoir properties, such as permeability (k), skin factor (s), drainage area (A), etc. PTA is proved to be a reliable method of estimating reservoir properties. However, PTA is usually costly. In additional, disruption to the well production is often resulted when generating the pressure-time data required for PTA, which cause additional loss to the company.

RTA provides a mean of estimating reservoir properties. Differ from PTA which required short pressure-time data, RTA required only rate-time data which are readily available and does not cause disruption to well production. However, RTA are only applicable when there is natural decline in the production rate of the well.

The equations for both PTA and RTA are derived from Radial Diffusivity Equation. Thus, theoretically both methods are expected to yield close results. It is therefore of interest to study whether in real case, these two different approaches could be utilize to obtain sufficiently close reservoir properties. If the results are reasonably close with each other, RTA may emerge as a replacement method for well test in determining reservoir properties.

1.3 Objective and Scope of Study

The objectives of this project are:

i. To investigate whether the two independent methods (Rate Transient Analysis and Pressure Transient Analysis) yield close results on reservoir properties such as permeability (k) and skin (s).

ii. To assess the suitability of Rate Transient Analysis as a substitute for Pressure Transient Analysis.

Some scopes of study in this projects are:

i. Real data from the field are used in this project.

ii. Permeability (k) and skin factor (s) are used as the main reservoir parameters to be compared in this project.

iii. Kappa Saphir and Topaze software are used to perform PTA and RTA respectively.

CHAPTER 2: LITERATURE REVIEW AND THEORY

This chapter discusses the theory and past researches done on PTA and RTA.

2.1 Pressure Transient Analysis (PTA)

PTA is widely applied in the petroleum industry to investigate reservoir parameters. For example, Pressure Draw-Down (PDD) test is by operating the well at a fixed production rate and monitoring its pressure response. On the other hand, Pressure Build-Up (PBU) test is done by first producing the well at a constant production rate for a period of time, then shut in the well at the surface and record the pressure response in the wellbore. An advantage of PBU test over other pressure transient test is that its rate (q=0 STB/Day) can be accurately controlled during the test. However, PBU test results in a loss of revenue as the well is shut in while the test is being carried out.

There are a few techniques that could be used to analyze the pressure versus time data collected from PTA. Among these techniques, Horner's Plot (Semi-log analysis of PBU), Pressure vs Logarithm of Time Plot (Semi-log analysis of PDD) and Bourdet-Gringarten Type Curve Analysis are the most widely technique being applied.

Initially, semi-log plot of Wellbore Pressure versus Time are designed to analyze PDD test. Theoretically, the plot will generate a straight line and the slope of the straight line can be used to estimate reservoir parameters using Equation 2 to Equation 4 in Appendix A. Horner (1951) in his paper present an approximation from superposition principle that could be used to model pressure buildup. The equation that Horner proposed is shown in Appendix A as Equation 5. Horner's equation suggests that a plot of shut in pressure, p_{ws} against horner time, $(\frac{t_p+\Delta t}{\Delta t})$ on a semilog graph as shown in Figure 1 (Appendix B) will generate a straight line. The slope of the straight line, m can then be used to calculate permeability and skin of the well using Equation 6 and Equation 7.

In reality, this straight line is often distorted by near wellbore effect and boundary effect. John (1982) in his book, describes that in analyzing actual well test data, the semi-log plot can be divided into three part: i) Early Time Region (ETR), ii) Medium Time Region (MTR) and iii) Late Time Region (LTR) as shown in Figure 1. The pressure versus time data in the ETR and LTR are distorted by near wellbore and boundary effect respectively and as such cannot be used to investigate the reservoir properties. Thus, the greatest challenges of semi-log plot analysis lies in identifying the MTR.

Ramey (1970), Agarwal et al. (1970) and Gringarten et al. (1979) also investigate into the use of well test data to investigate reservoir properties by using type curve analysis. The idea was first investigated by Agarwal et al. In their research, a log-log plot of dimensionless pressure, P_D versus dimensionless time, t_D is generated for different value of time (t), storage constant (C_{sD}) and skin effect (s). The resulted type curve is a graphical representation of RDE solutions that are grouped by different values of C_{sD}. For each C_{sD} stem, multiple curves are drawn for different values of s. This type curve of Agarwal et al. has an issue of uniqueness as the curves for different value of C_{sD} and s can have very similar shape with each other.

Gringarten et al. then further developed then type curve by introducing the dimensionless time group $\left(\frac{t_D}{C_D}\right)$ as the plotting variable. He also included the pressure derivative plot introduced by Bourdet et al.(1989) into his type curve. The resulted composite type curve was thus referred to as the Bourdet Gringarten type curve (Figure 2, Appendix C), the most commonly applied type curve in well test analysis today.

The Bourdet Gringarten type curve can be divided into three portion for analyzing:

- The first portion, I, all the curves merge to a straight line with unit slope of 1 (45^0). This is the portion of the data which is distorted by the near wellbore effect.

- The second portion, II is the transition period between the wellbore storage effect and the radial flow. In this portion, the pressure plot and the its derivative plot spread from each other, where the derivative curve slopes downwards after the peak of the graph. The peak of the graph depends on the value of C_De^{2s}.

- In the third portion, III all of the derivative curves and the pressure plots merge together into a horizontal line. This horizontal line is a characteristic straight line describing infinite-acting radial flow, and hence can be used to identified MTR and determine the reservoir characteristics.

2.2 Rate Transient Analysis (RTA)/ Advanced Decline Curve Analysis

Decline curve analysis is used to forecast future performance of a reservoir based on its past production data. Conventional decline curve analysis are mostly developed based on the works of Arps (1945), which illustrates the empirical relationships of production rate versus time, given by Equation 8 in Appendix A.

The concept of conventional decline curve analysis is to fit past production data to a straight line using empirically derived exponential, hyperbolic or harmonic function and use the straight line to predict future performances of the well. The objective of conventional decline curve analysis is always to predict future oil rate and estimated the ultimate recovery of the well. It does not provide information on reservoir or well parameters. This method make an assumption that the operating conditions of the well remain unchanged in the future and it totally ignores the flowing pressure data in its analysis. Therefore, conventional decline curve analysis always yield unreliable matches and inconsistent results.

An advanced approach of decline curve analysis is established when Fetkovich (1980) introduced the concept of using type curve to analyze rate-time data. Differ from the conventional decline curve analysis, Fetkovich approach of decline curve analysis is capable of providing information on reservoir characteristics and parameters. In his research in 1980, Fetkovich introduced dimensionless variables: dimensionless flow rate (q_D) and dimensionless time (t_D) as shown by Equation 9 and Equation 10 in Appendix A and apply constant pressure at inner boundary principle in his calculation. Fetkovich then demonstrated that this analytical solutions and the empirical solutions from Arp's Equation can be compiled into a log-log plot to generate a type curves.

In Fetkovich Type Curves (Figure 3, Appendix D), all curves coincides at $t_D = 0.3$. Any data to the left side of $t_D = 0.3$ will be concaving upwards and representing transient flow regime. On the other hand, data to the right side of $t_D = 0.3$ will be concaving downwards and representing boundary dominated flow. Fetkovich type curve is able to match production data during both transient and boundary dominated period. The transient flow regime of Fetkovich type curve provides the solutions for reservoir characterization, while the boundary dominated region provides forecast on future well performance. By selecting a match point with Fetkovich type curve, the permeability (k), skin (s) and drainage area of the reservoir can be calculated using Equation 11 to Equation 14 in Appendix A. However, Fetkovich's work is limited to the assumption of constant flowing pressure.

Blasingame, McCray and Lee (1991) did work to overcome the limitation of Fetkovich's work: to find a way of analyzing decline production data where the flowing bottomhole pressure varies. In their paper, they sought functions that could transform the production data for a system with changing rate or pressure drop into an equivalent system produced at a constant bottomhole pressure. The approach that Blasingame et al. apply are also known as the "constant rate analysis approach".

Palacio and Blasingame (1993) introduced a solution for the general case of changing rate or pressure drop for single phase liquid or gas flow. They presented a new technique to solve gas problem by converting gas production data with changing rate and pressure into equivalent constant rate liquid data. In reaching their results, Palacio and Blasingame combines three elements: material balance relation, pseudosteady-state equation and normalized material balance time function in deriving their equation for decline curve analysis.

The Blasingame Type Curve (Figure 4, Appendix E) have identical format with Fetkovich type Curve, but contains of three type of curve and modified dimensionless variables. The x-axis is changed to modified dimensionless decline time function and the y axis is changed to 3 types of plotting function:

i. Normalized rate curve, q_{Dd} (Equation 18)

ii. Integral function, $(q_{Dd})_i$ (Equation 19)

iii. Derivative of the Integral function, $(q_{Dd})_{id}$ (Equation 20)

The reservoir parameters can then be calculated by using Equation 21 to Equation 26.

Agarwal and Gardner introduce several methods of analysis decline curve performance of a reservoir based on modern decline analysis theory. Their methods are: i) Rate versus Time type curves, ii) Cumulative Production versus Time type curve and iii) Rate vs Cumulative Production type curves. Agarwal and Gardner's Rate versus Cumulative Production type curves are different from conventional type curves as they are plotted on Cartesian Scale instead of Log-Log Scale. This method is designed to analyzed boundary dominated data. Hence, it is used to estimate fluid-in-place instead of permeability and skin.

CHAPTER 3: METHODOLOGY/PROJECT WORK

This chapter presents the methodology/procedure used in completing this project.

3.1 Methodology

i. A production well, known as Well A is selected such that it have produced for a long period of time and have undergo naturally decline in its production rate. Historical pressure and rate data of Well A (a production well) is gathered.

ii. Quality checking were performed on the data. Noise and anomalies in the data were screened and the causes were investigated. If necessary, the anomalies and noises were filtered out.

iii. Rate Transient Analysis/ Production Data Analysis were performed on Well A to determine the reservoir properties (permeability, skin factor, initial reservoir pressure). Commercial software Ecrin Topaze was used for this work.

iv. Pressure Transient Analysis were performed on Well A to determine reservoir properties (Permeability, skin factor, initial reservoir pressure). Commercial software Ecrin Saphir was used for this work.

v. The results from both the methods were compared and analyzed.

3.2 Proposed Milestones

a) Data Gathering and Processing (Week 14 FYP1- Achieved)
b) Pressure Transient Analysis (Week 2 FYP2-Achieved)
c) Production Data Analysis (Week 4 FYP2-Achieved)
d) Results Analysis (Week 6 FYP2-Achieved)

3.3 Gantt Chart

Final Year Project I														
Task \ Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Selection of project topic	■	■												
Literature review findings		■	■	■	■									
Extended Proposal preparation					■	■								
Data Gathering						■	■	■	■	■	■			
Proposal defense								■	■					
Data Processing										■	■	■		
Pressure Transient Analysis													■	■
Interim Draft Report preparation												■	■	
Draft Report preparation													■	■

Final Year Project II														
Task \ Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Pressure Transient Analysis	■	■												
Rate Transient Analysis		■	■	■										
Comparing and Analyzing Results					■	■	■							
Progress Report Preparation						■	■							
Pre-SEDEX Preparation								■	■	■				
Draft Report										■	■	■		
Dissertation											■	■	■	
Technical Paper													■	
Oral Presentation													■	■

CHAPTER 4: RESULTS AND DISCUSSION

This chapter presents the analysis and discussions of the results obtained through this project.

4.1 Results

4.1.1 Pressure Transient Analysis

A number of PBU and PDD Analysis data can be obtained throughout the five years of Well A's production life. However, only three sets of PBU analysis and two sets of PDD analysis were chosen and presented such that their test durations were long enough to obtain a reliable set of data. The details of the PBU and PDD test being chosen are as followed:

Table 4.1: PBU and PDD chosen for Pressure Transient Analysis

PTA	Test	Date Start	Date End	Duration (Hours)
PBU	BU15	15-07-10	22-07-10	170
	BU38	07-07-11	12-07-11	65
	BU44	07-03-12	09-03-12	135
PDD	DD10	05-06-09	27-06-09	528
	DD15	22-07-10	25-07-10	72

Each of these PTA were analyzed using Type Curve Analysis. The results are presented in the following section.

A) PBU15

PBU15 started from 15 July 2010 to 22 July 2010, lasting for a duration of 170 hours. Well A had been producing at an oil rate of 13111 STB/D for 352 hours before the test.

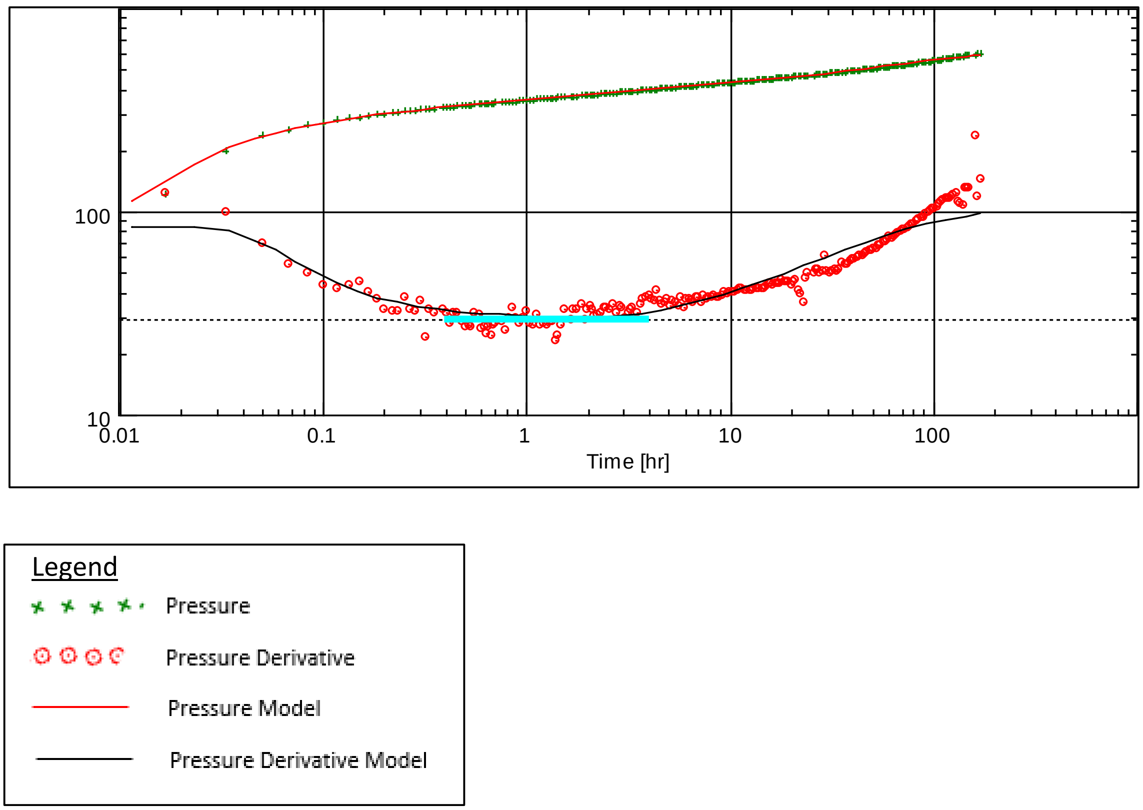


Figure 4.1: Log-Log Plot/Type Curve Matching of PBU15

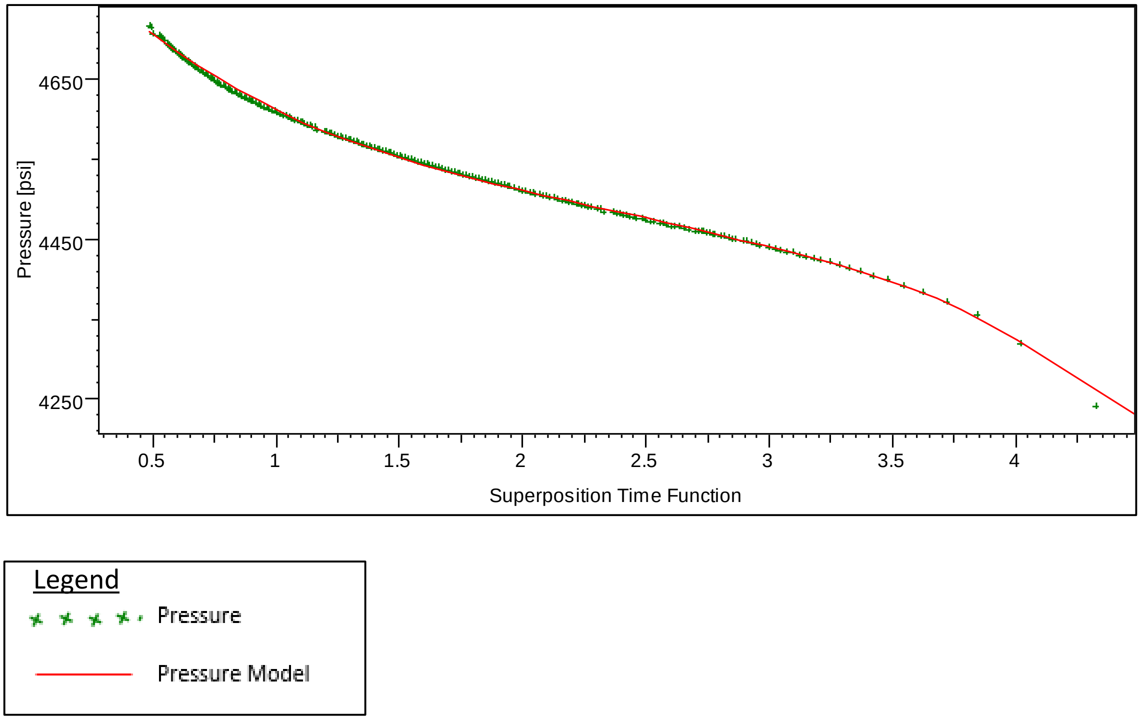


Figure 4.2: Horner's Plot for PBU15

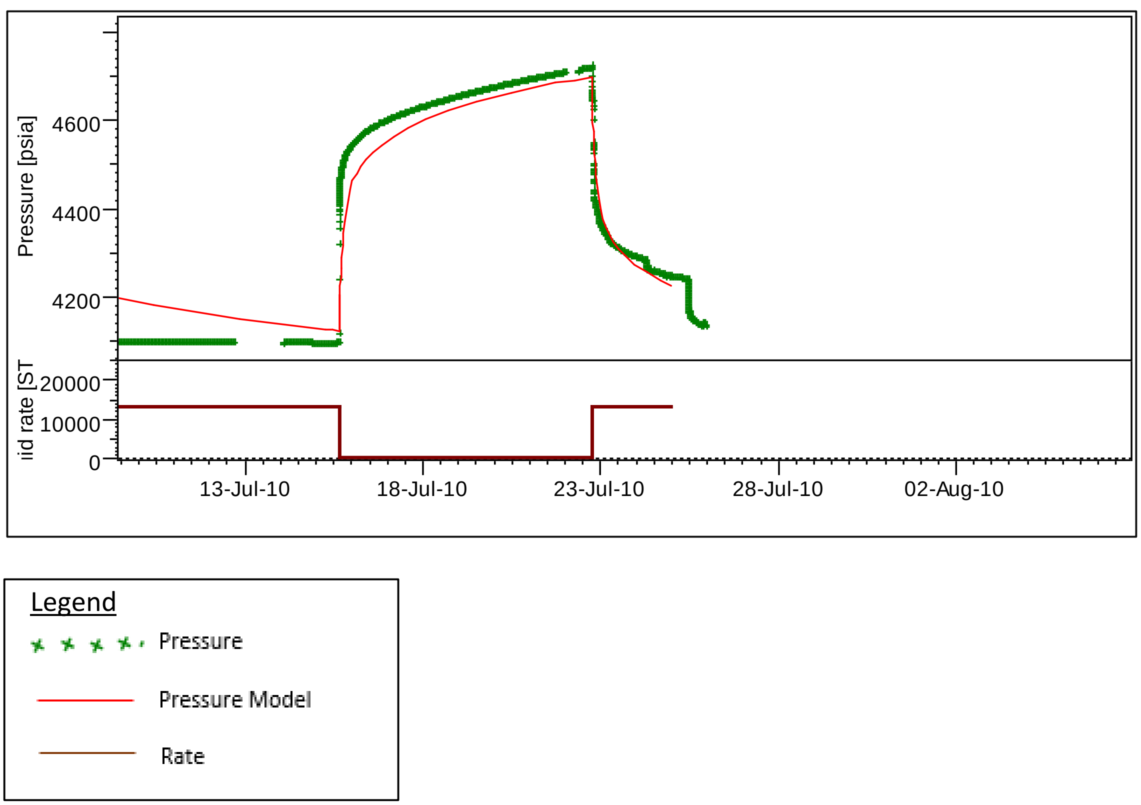


Figure 4.3: History Plot of PBU15

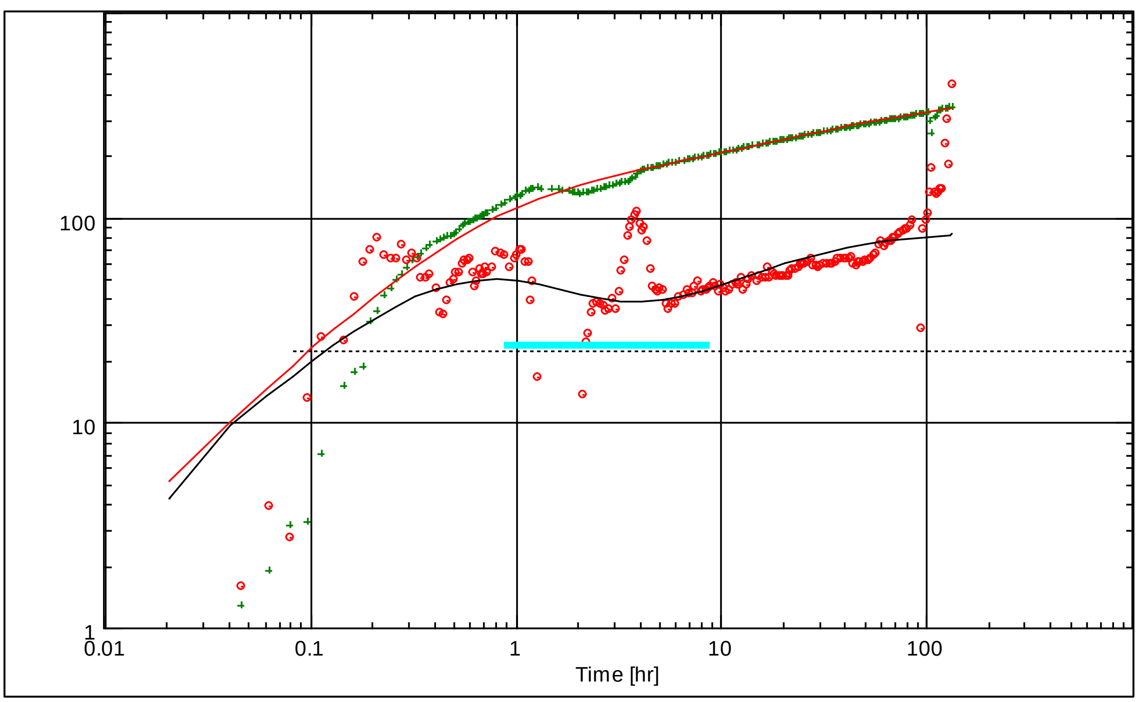
Figure 4.1, 4.2 and 4.3 shows the log-log plot, Horner's plot and history plot of PBU15. As shown in the figures, the data obtained are of good quality and consist of not much noise. The Infinite Acting Radial Flow (IARF) period is clearly visible in both the log-log plot and Horner's plot. Hence, a good match is obtained from the type curve analysis. The estimated reservoir parameters from PBU15 is presented in Table 4.2 below.

Table 4.2: Reservoir Parameters Results from Log-Log Plot/Type Curve Analysis of PBU15

Parameters	Value
Well Deliverability, kh (mD.ft)	15100
Permeability, k (mD)	174
Skin Factor, s	-0.219

B) PBU38

PBU38 started from 7 July 2011 to 12 July 2011, lasting for a duration of 65 hours. Well A had been producing at an oil rate of 6210 STB/D for 53 hours before the shut in.



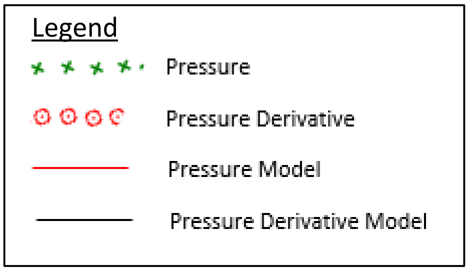


Figure 4.4: Log-Log Plot/Type Curve Matching of PBU38

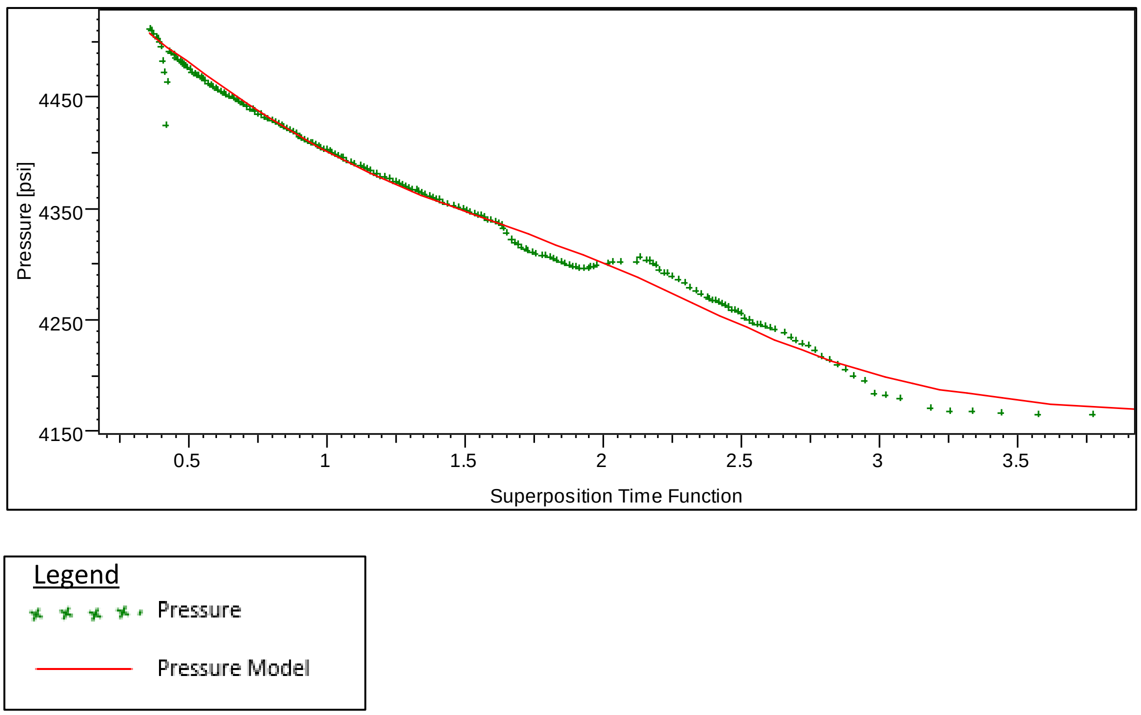


Figure 4.5: Horner's Plot for PBU38

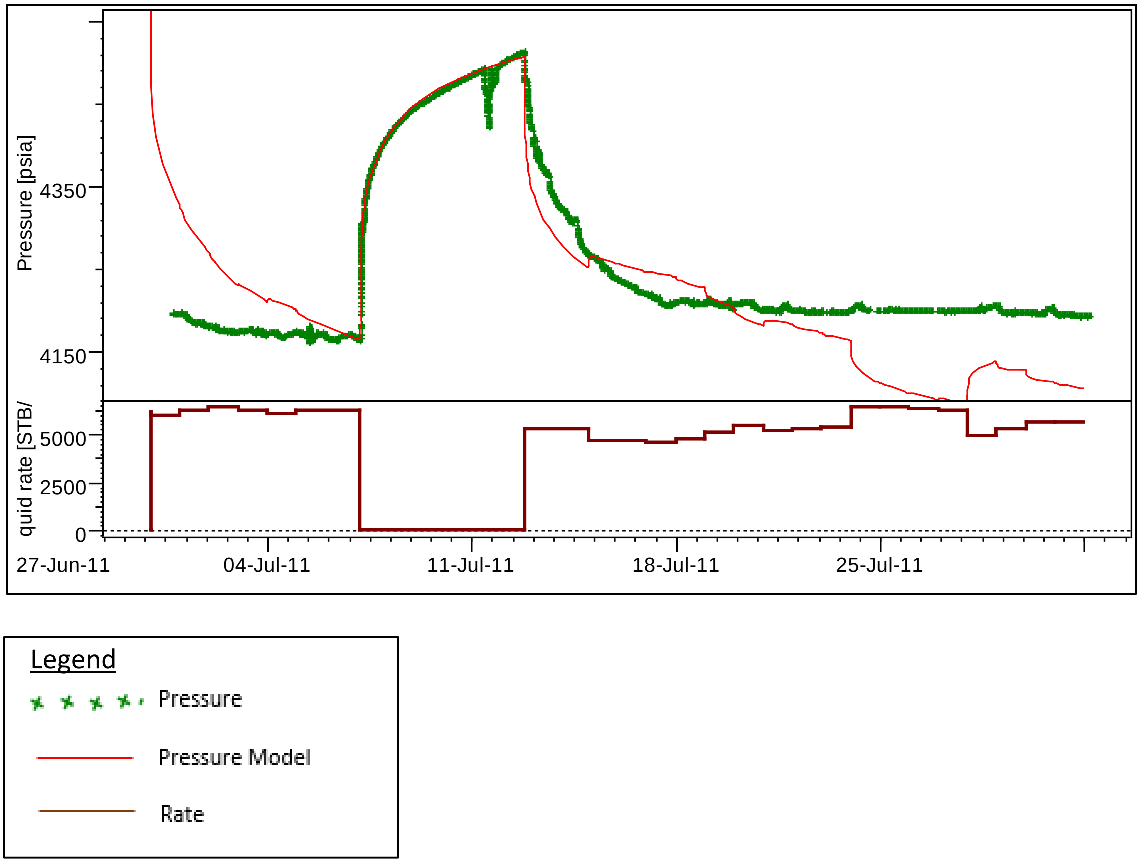


Figure 4.6: History Plot of PBU38

Figure 4.4, 4.5 and 4.6 show the log-log plot, Horner's plot and history plot of PBU38 respectively. From these figures, it can be seen that the early time data are quite noisy and seem to be disrupted by some factors. However, the IARF period is able to be identified through the log-log plot and the Horner's plot. A satisfactory match can thus be obtained. The simulation run of the model as presented in Figure 4.6 also shows a good match between the simulated pressure and the actual pressure response observed. The estimated reservoir parameters from PBU38 is presented in Table 4.3 below.

Table 4.3: Reservoir Parameters Results from Log-Log Plot/Type Curve Analysis of PBU38

Parameters	Value
kh (mD.ft)	9520
Permeability, k (mD)	110
Skin Factor, s	-2.82

C) PBU44

PBU 44 started from 6 March 2012 to 9 March 2012, lasting for a duration of 63 hours. Well A had been producing at an oil rate of 5150 STB/D for 456 hours before the test.

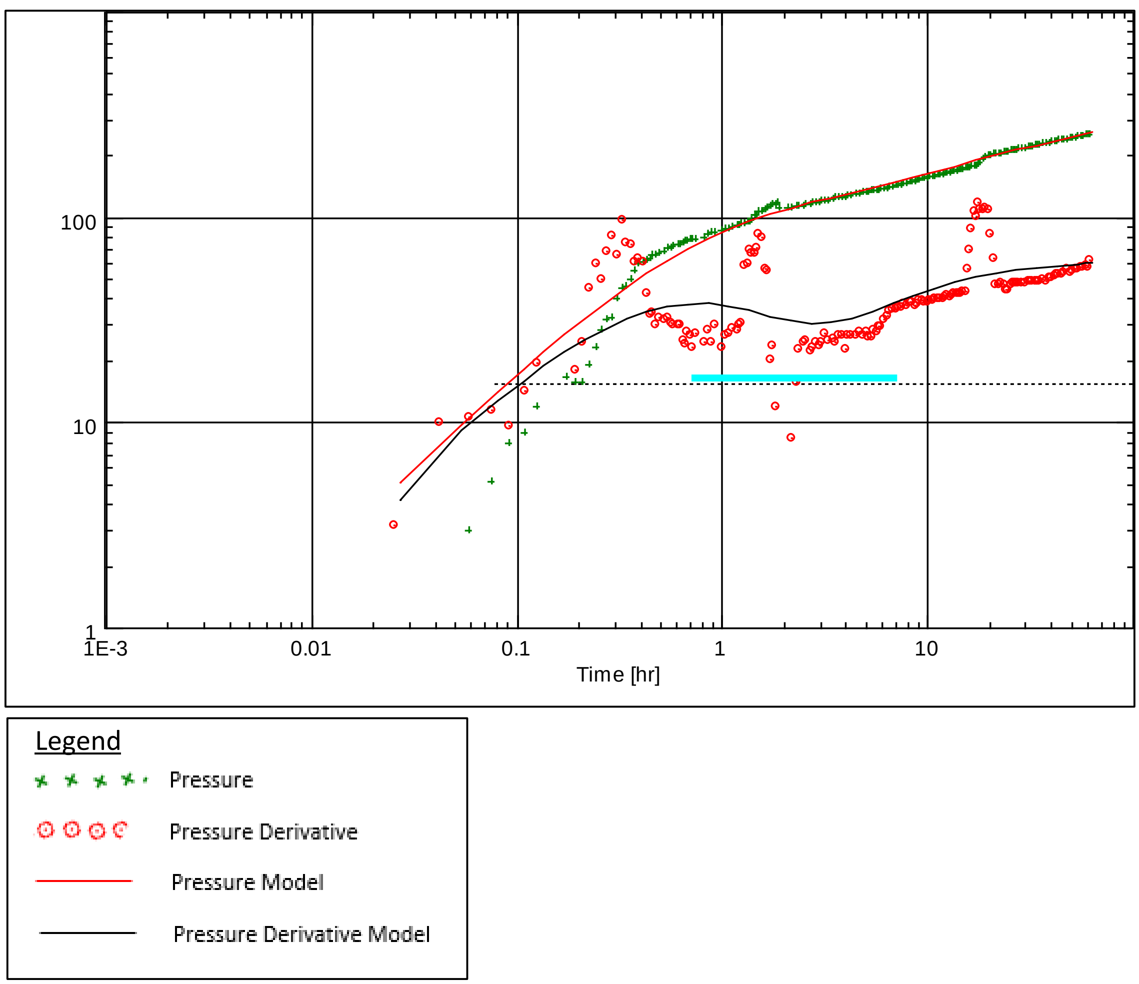


Figure 4.7: Log-Log Plot/Type Curve Matching of PBU44

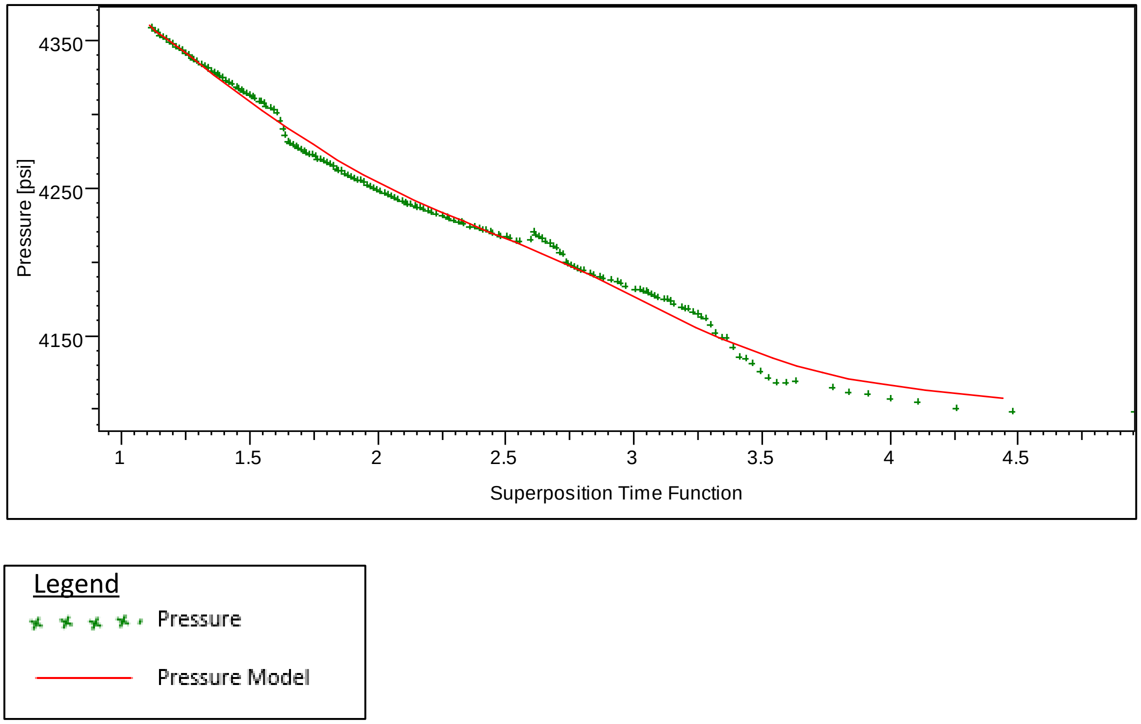


Figure 4.8: Horner's Plot for PBU44

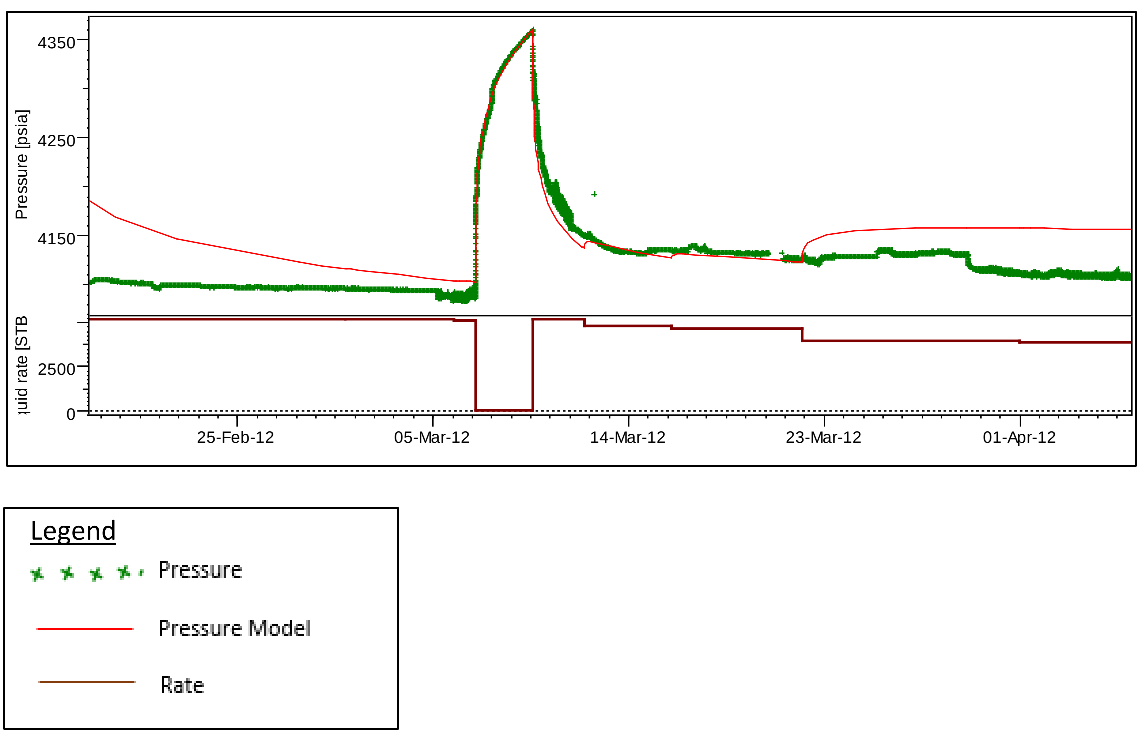


Figure 4.9: History Plot of PBU44

Figure 4.7, 4.8 and 4.9 show the log-log plot, Horner's plot and history plot of PBU44 respectively. From Figure 4.7 and 4.8, it can be seen that the quality of PBU44 is similar with PBU38, whereby the early time data are noisy and disrupted. Nevertheless, the IARF period is able to be identified through the log-log plot and the Horner's plot, and a good match between the simulated pressure and the actual pressure is achieved in the simulation run as presented in Figure 4.9. Hence, the quality of PBU44 results is good. The estimated reservoir parameters from PBU44 is presented in Table 4.4 below.

Table 4.4: Reservoir Parameters Results from Log-Log Plot/Type Curve Analysis of PBU44

Parameters	Value
kh (mD.ft)	11300
Permeability, k (mD)	130
Skin Factor, s	-2.6

D) PDD10

PDD10 took place from 5 June 2009 to 27 June 2009, lasting for a period of 531.758 hours. The well were shut in for a period of 189 hours and was producing at an average oil rate of 14500 STB/D during the PDD test.

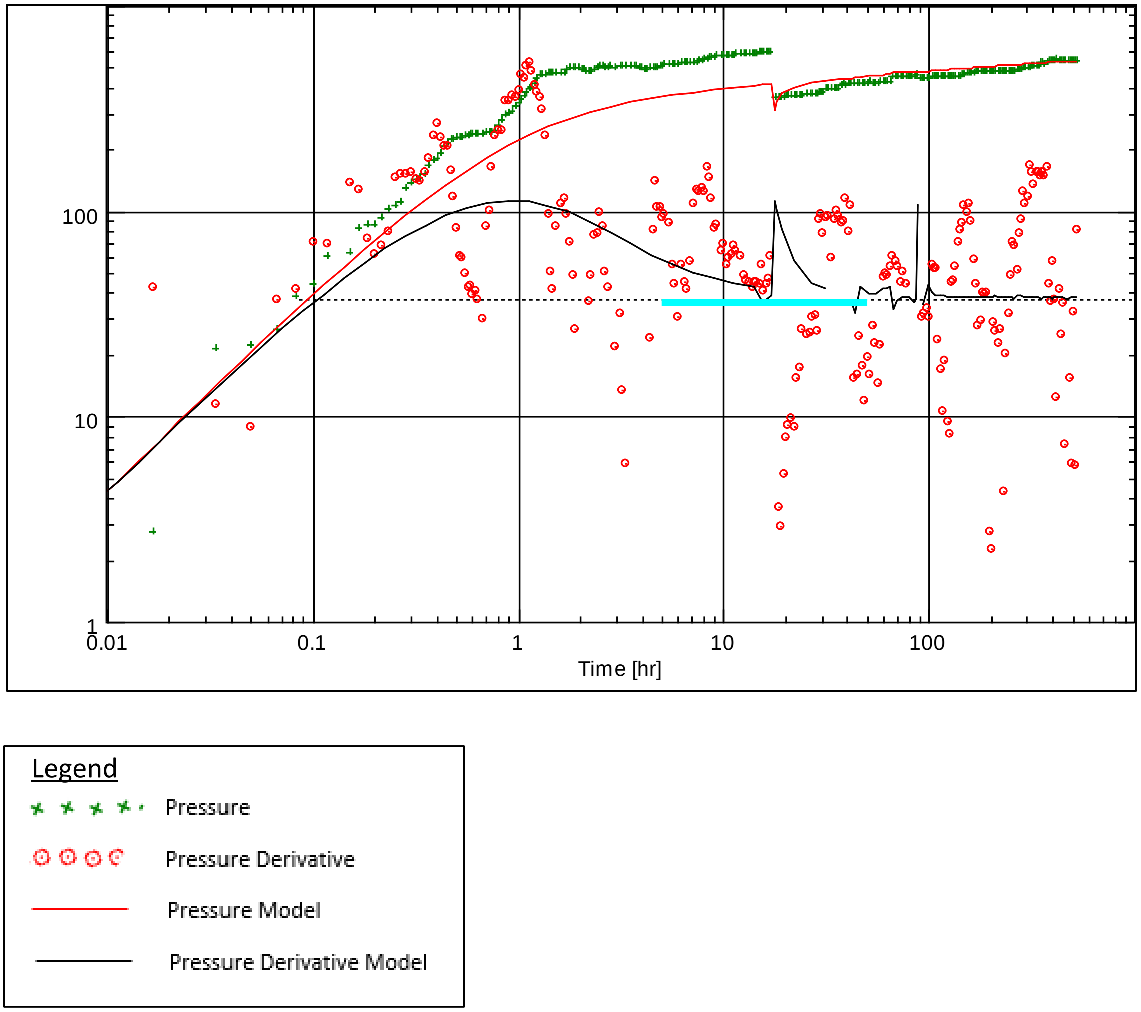
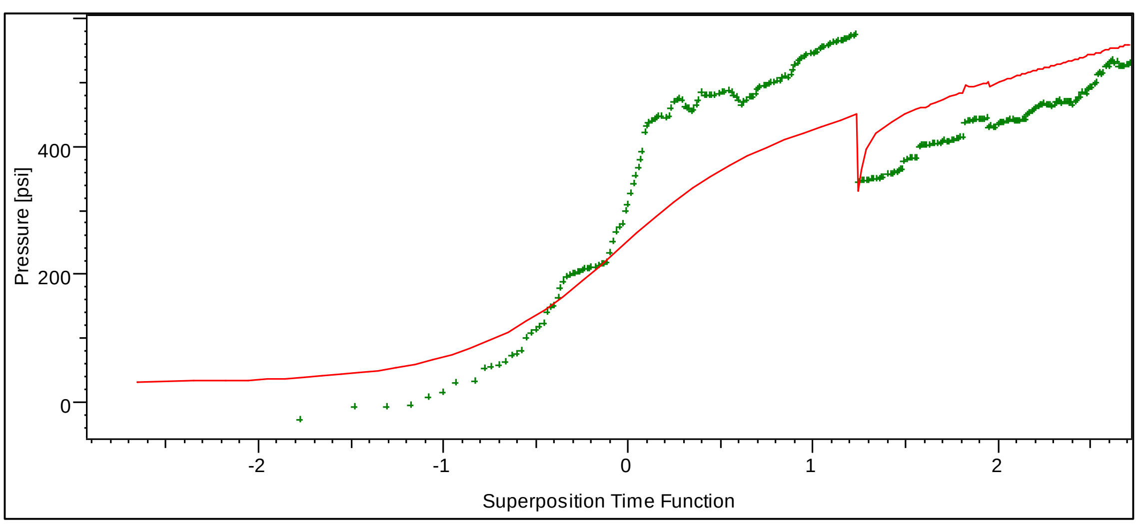


Figure 4.10: Log-Log Plot/Type Curve Matching of PDD10



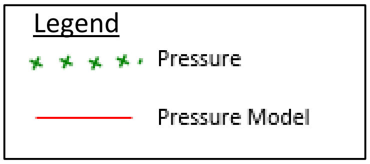


Figure 4.11: Semi-Log Plot of PDD10

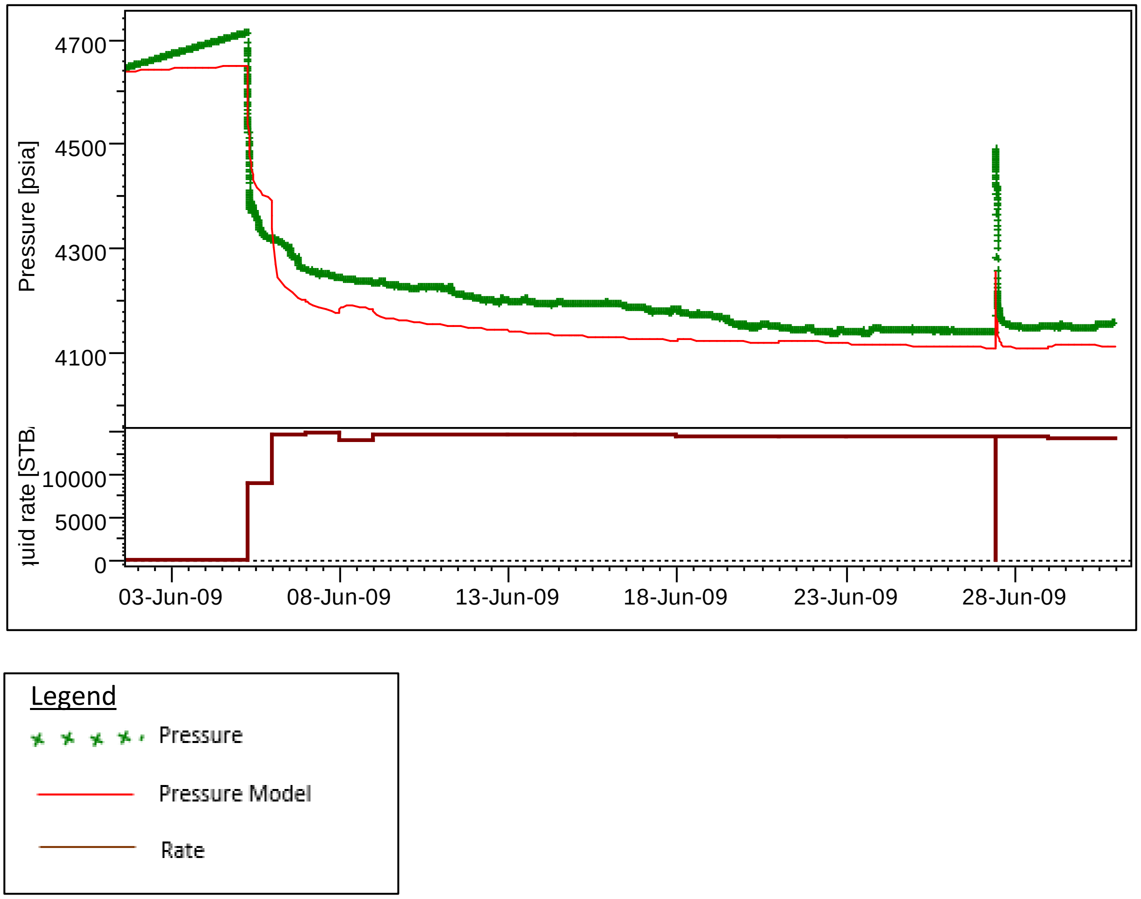


Figure 4.12: History Plot of PDD10

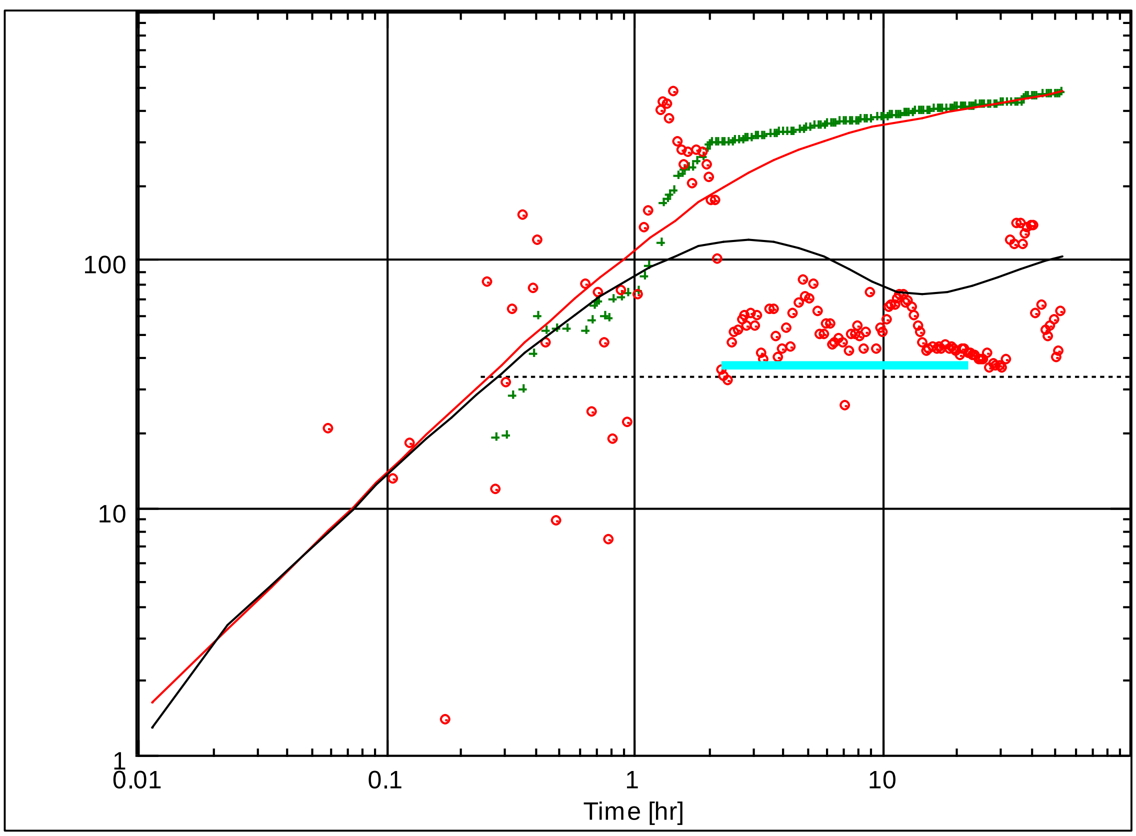
Figure 4.10, 4.11 and 4.12 show the log-log plot, semi-log plot and history plot of PDD10 respectively. From Figure 4.10 and 4.11, it is very obvious that the data set of PDD10 consists of a lot of noises and disruptions. The IARF period cannot be clearly identified through the log-log plot and the semi-log plot. Hence, a horizontal straight line indicating IARF is drawn based on the overall trend of the late time pressure data in the derivative plot. This horizontal straight line iss used as the basis for this analysis. Figure 4.12 shows a satisfactory match between the simulated pressure and the actual pressure from the simulation run. Hence, it is concluded that the quality of PDD10 results is satisfactory. The reservoir parameters estimated from PDD44 is presented in Table 4.5 below.

Table 4.5: Reservoir Parameters Results from Log-Log Plot/Type Curve Analysis of PDD10

Parameters	Value
kh (mD.ft)	13200
Permeability, k (mD)	152
Skin Factor, s	-2

E) PDD15

PDD15 took place from 22 July 2010 to 25 July 2012, lasting for a duration 532 hours. The well had been shut-in for a period of 171 hours and was producing at an oil rate of 13000 STB/D before the test.



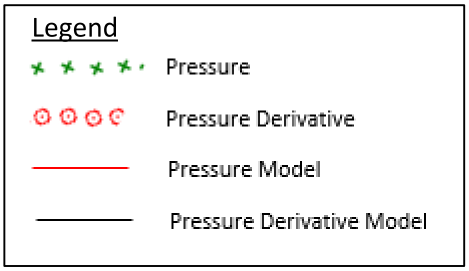


Figure 4.13: Log-Log Plot/Type Curve Matching of PDD15

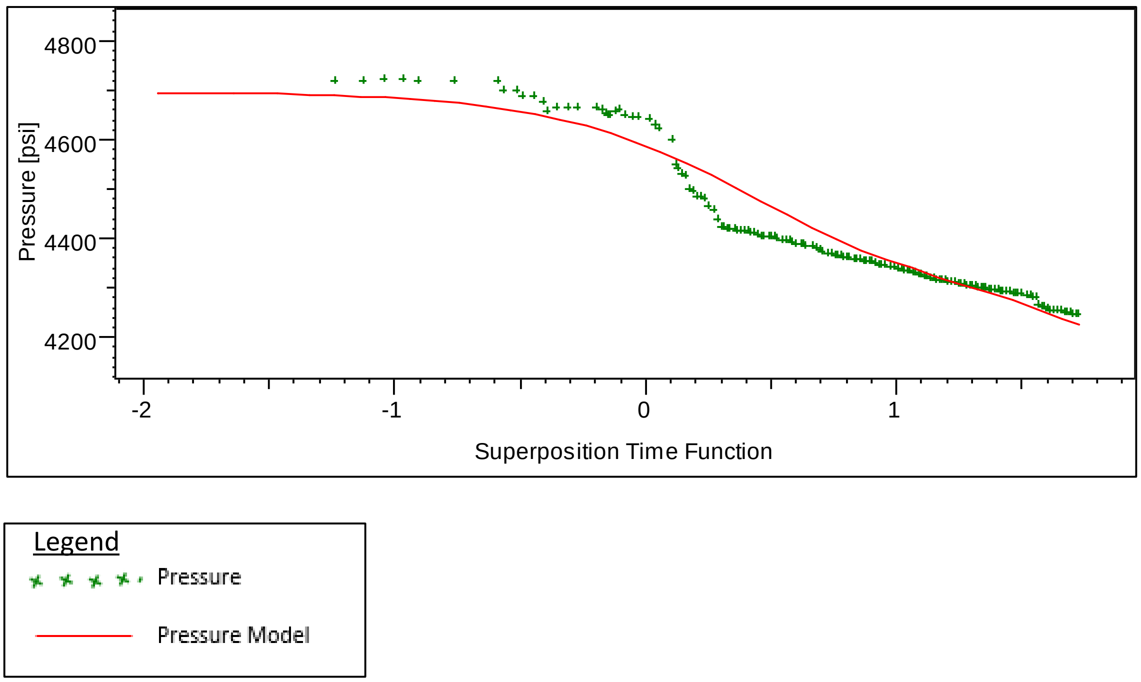


Figure 4.14: Semi-Log Plot of PDD15

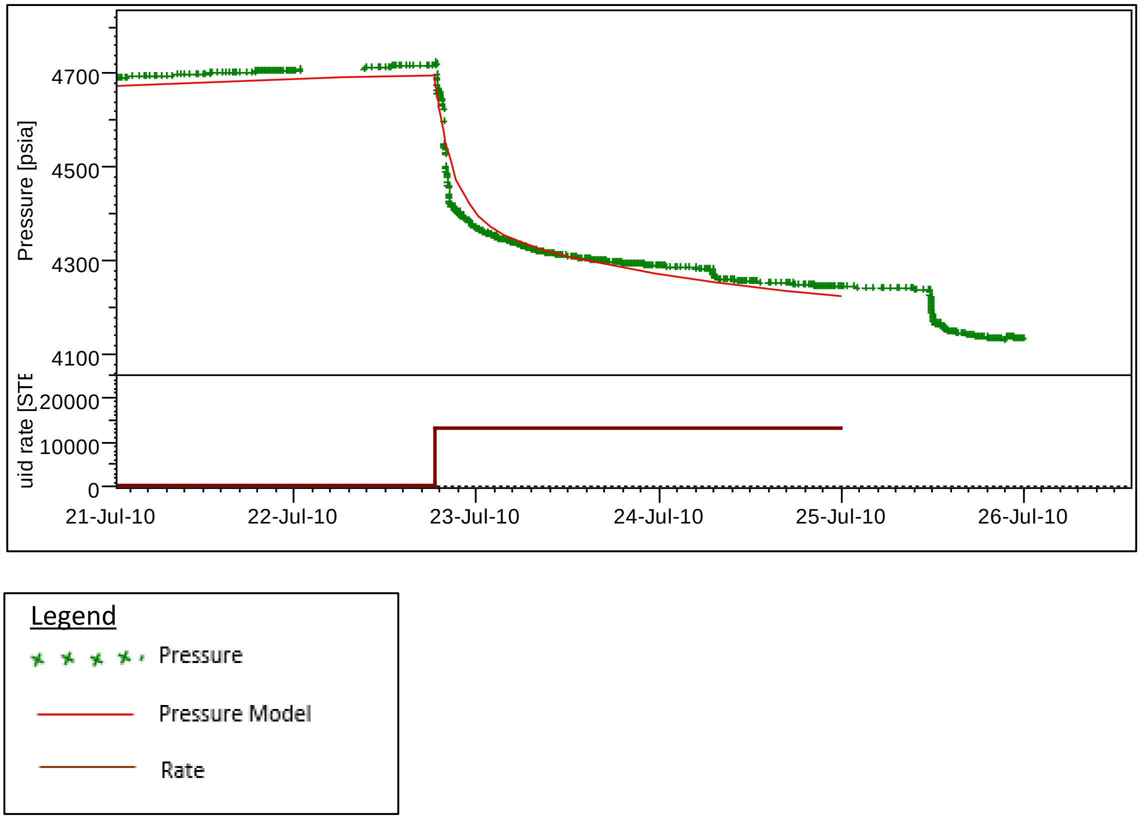


Figure 4.15: History Plot of PDD15

Figure 4.13, 4.14 and 4.15 show the log-log plot, semi-log plot and history plot of PDD15 respectively. It can be seen from Figure 4.13 and 4.14 that the early time data of PDD15 are noisy and disrupted. However, the straight line indicating IARF period is able to be identified through the log-log plot and semi-log plot. The history plot as presented in Figure 4.15 also shows a good match between the simulated pressure and the actual pressure. Hence, the overall quality of PDD15 analysis is good. The estimated reservoir parameters from PDD15 is presented in Table 4.6 below.

Table 4.6: Reservoir Parameters Results from Log-Log Plot/Type Curve Analysis of PDD15

Parameters	Value
kh (mD.ft)	13300
Permeability, k (mD)	153
Skin Factor, s	-1.75

F) Summary of PTA Results

Table 4.7 below summarize the results obtained through the PTA of PBU15, PBU38, PBU44, PDD10 and PDD15.

Table 4.7: Summary of PTA Results

Parameter	Pressure Transient Analysis					
	PBU15	PBU38	PBU44	PDD10	PDD15	Average
Well Deliverability, kh (mD.ft)	15100	9520	11300	13200	13300	12484
Permeability, k (mD)	174	110	130	152	153	143.8
Skin, s	-0.219	-2.82	-2.6	-2	-1.75	-1.88
Quality of the Analysis	Good	Good	Good	Satisfactory	Good	-

As summarized in Table 4.7 above, the well deliverability (kh), permeability (k) and skin (s) estimated from the 5 PTAs are in the range of 9520 mD.ft to 15100 mD.ft, 110 mD to 174 mD and -2.82 to -0.219 respectively. The average permeability and skin factor obtained from all the PTA analysis are 143.8 mD and -1.88 respectively. PBU15, PBU38, PBU44 and PDD15 are considered as good analysis as the IARF period are able to be clearly identified in their log-log plots. PDD10 is considered as a satisfactory analysis only because the IARF period cannot be clearly visible in its log-log plot.

4.1.2 Rate Transient Analysis

Well A undergo decline in its oil production rate approximately 2 years after its production life. Figure 4.6 shows the production rate throughout the production life of Well A together with its associate pressure data. It can be observed that Well A experience an obvious decline production rate from January 2011 to June 2011. Hence, the rate and pressure data during this period was isolated and analyzed using the Fetkovich's Type Curve and Blasingame's Type Curve Analysis.

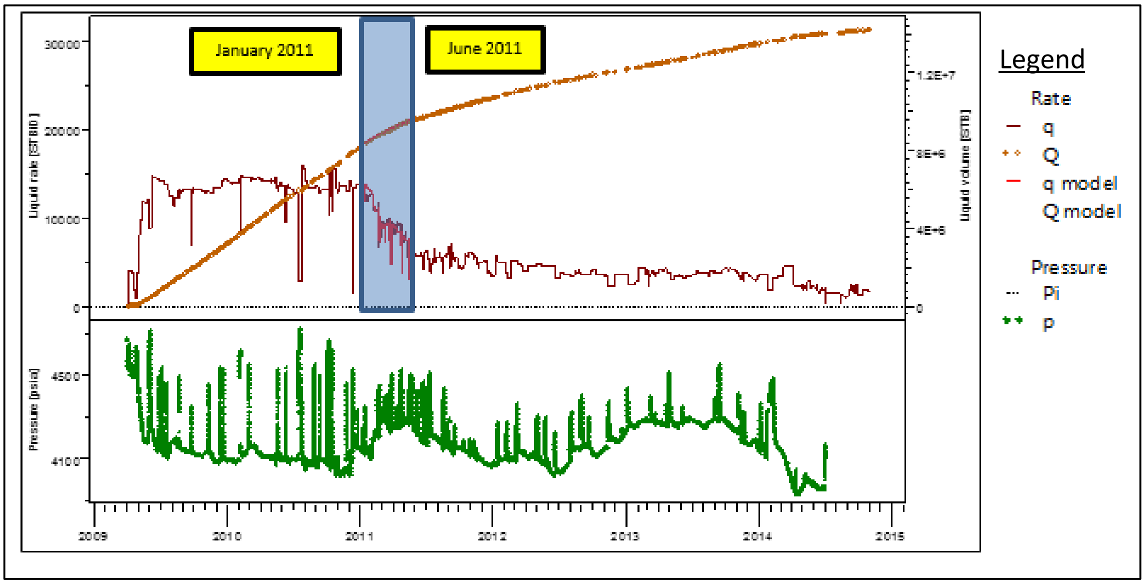


Figure 4.16: Production Rate and Pressure History Plot of Well A

A) Fetkovich's Type Curve Analysis

The matching and analysis results of Fetkovich's Type Curve Analysis were presented in Figure 4.17 and Table 4.8 below.

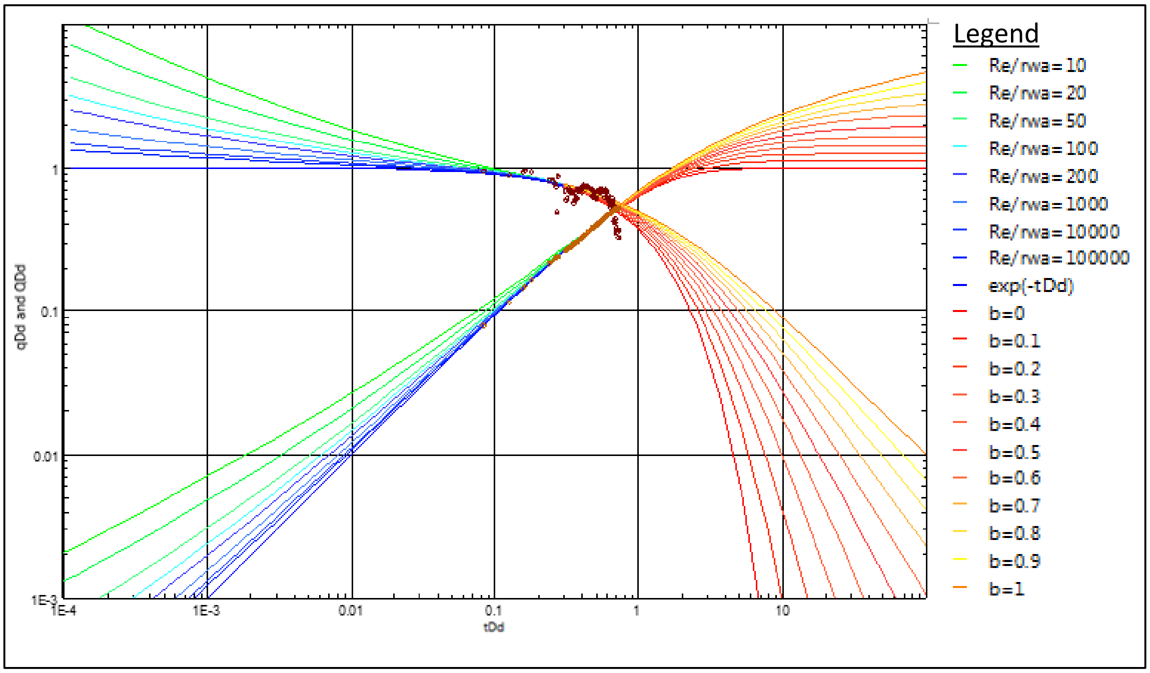


Figure 4.17: Fetkovich's Type Curve Matching

Figure 4.17 shows the results of Rate Transient Analysis by Fetkovich's Type Curve Matching. As shown in Figure 4.17, the quality of the type curve matching is good. The dimensionless flow rate, qDd and its derivative, QDd could match closely with the type curve. The results obtained from Fetkovich's Type Curve Matching is presented in Table 4.8 below.

Table 4.8: Reservoir Parameters Results from Fetkovich's Type Curve

Parameters	Value
kh (mD.ft)	18000
Permeability, k (mD)	208
Skin Factor, s	-1.08

B) Blasingame's Type Curve Analysis

The matching and analysis results of Blasingame's Type Curve Analysis were presented in Figure 4.18 below.

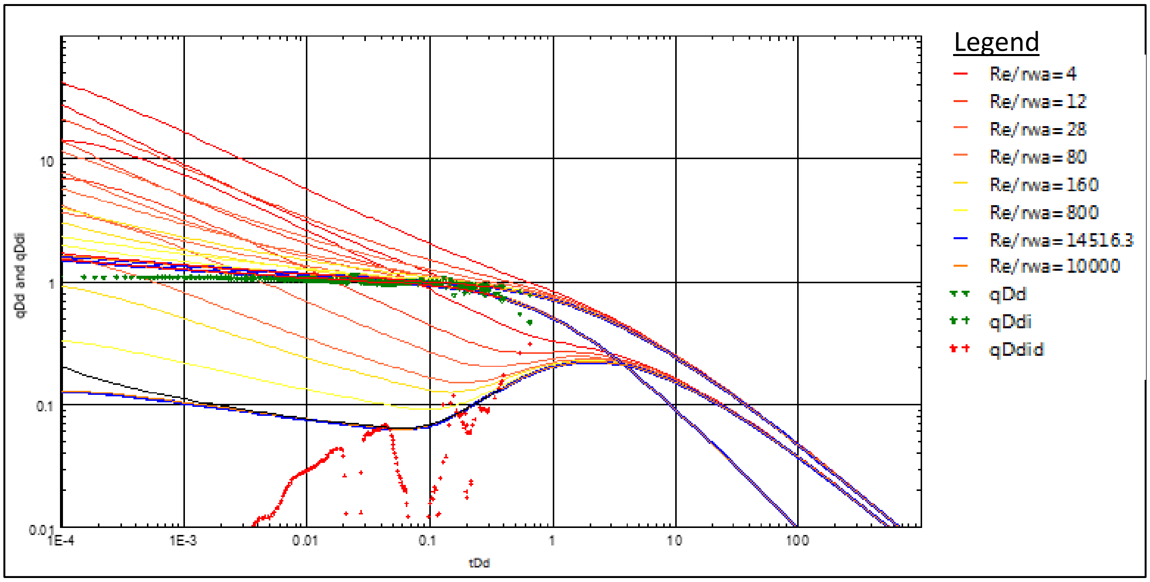


Figure 4.18: Blasingame's Type Curve Matching

Figure 4.18 shows the results of Rate Transient Analysis by Blasingame's Type Curve Matching. As shown in Figure 4.18, a good match between the observed data and the type curve is obtained. The dimensionless flow rate, qDd and its integral, qDdi could be closely match with the type curve. The derivative of the integral of dimensionless flow rate, qDdid, however, slightly deviate from those on the type curve. This mismatch of qDdid is mainly because of the noise in the production data. The results obtained from Blasingame's Type Curve Matching is presented in Table 4.9 below.

Table 4.9: Reservoir Parameters Results from Blasingame's Type Curve

Parameters	Value
kh (mD.ft)	10400
Permeability, k (mD)	119
Skin Factor, s	-0.293

C) Summary of RTA Results

Table 4.10 below summarize the results obtained through the Fetkovich's and Blasingame's Type Curve Analysis.

Table 4.10: Summary of RTA Results

Parameter	Rate Transient Analysis		
	Fetkovich	Blasingame	Average
kh (mD.ft)	18000	10400	14200
Permeability, k (mD)	208	119	163.5
Skin, s	-1.08	-0.293	-0.69
Quality of the Analysis	Good	Good	

As summarized in Table 4.10 above, the well deliverability (kh), permeability (k) and skin (s) estimated from Fetkovich's and Blasingame's method are in the range of 10400 mD.ft to 18000 mD.ft, 119 mD to 208 mD and -1.08 to -0.293 respectively. The average permeability and skin factor obtained from the RTA analysis are 163.5 mD and -0.69 respectively. Both analysis are considered as good analysis as the actual data are able to closely match with the type curve when plotted on the log-log graph.

4.1.3 Comparison of Results from Pressure Transient Analysis and Rate Transient Analysis

Table 4.11 below shows the comparison of the reservoir parameters obtained by applying pressure transient analysis and rate transient analysis on Well A.

Table 4.11: Comparison of Reservoir Parameters Results from Pressure Transient Analysis and Rate Transient Analysis

Parameter	Pressure Transient Analysis					Rate Transient Analysis	
	PBU15	PBU38	PBU44	PDD10	PDD15	Fetkovich's Type Curve	Blasingame's Type Curve
Well Deliverability, kh (mD.ft)	15100	9520	11300	13200	13300	18000	10400
Permeability, k (mD)	174	110	130	152	153	208	119
Skin, s	-0.219	-2.82	-2.6	-2	-1.75	-1.08	-0.293
Initial Reservoir Pressure, Pi (psia)	4830	4578	4516	4666.56	4840	4873	4873

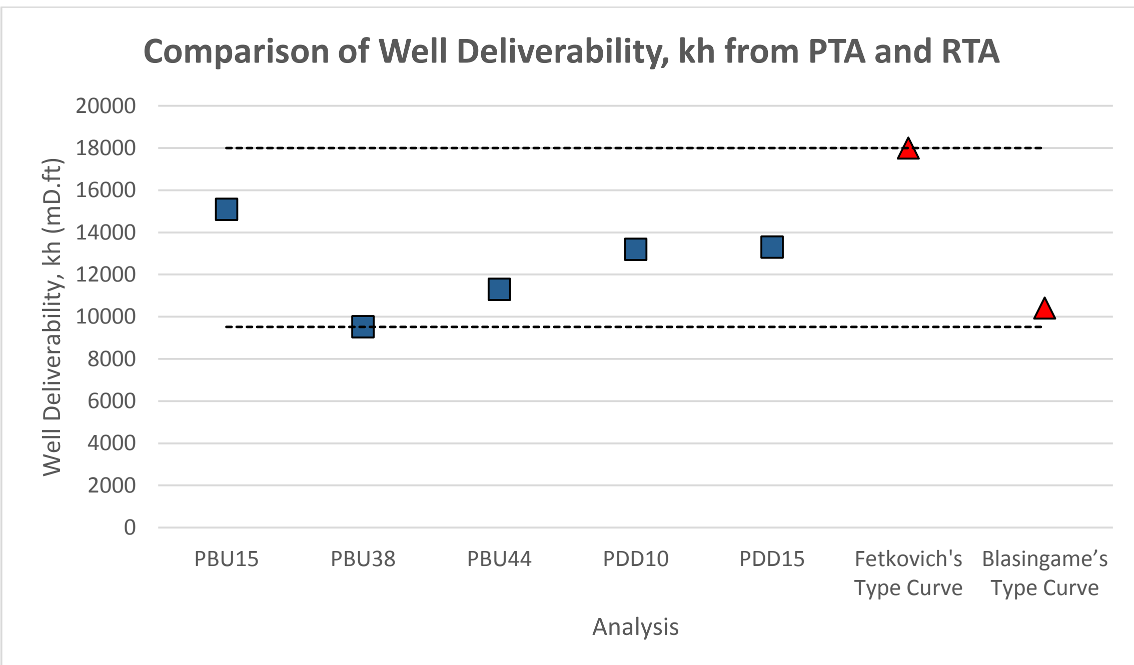


Figure 4.19: Comparison of Well Deliverability, kh from Pressure Transient Analysis (PTA) and Rate Transient Analysis (RTA)

Figure 4.19 shows the comparison of well deliverability, kh estimated by applying both PTA and RTA techniques. As presented in Figure 4.19, the five PTAs, Fetkovich's Type Curve Analysis and Blasingame's Type Curve Analysis estimated that the kh of the Well A is between the range of 9520 mD.ft to 18000 mD.ft.

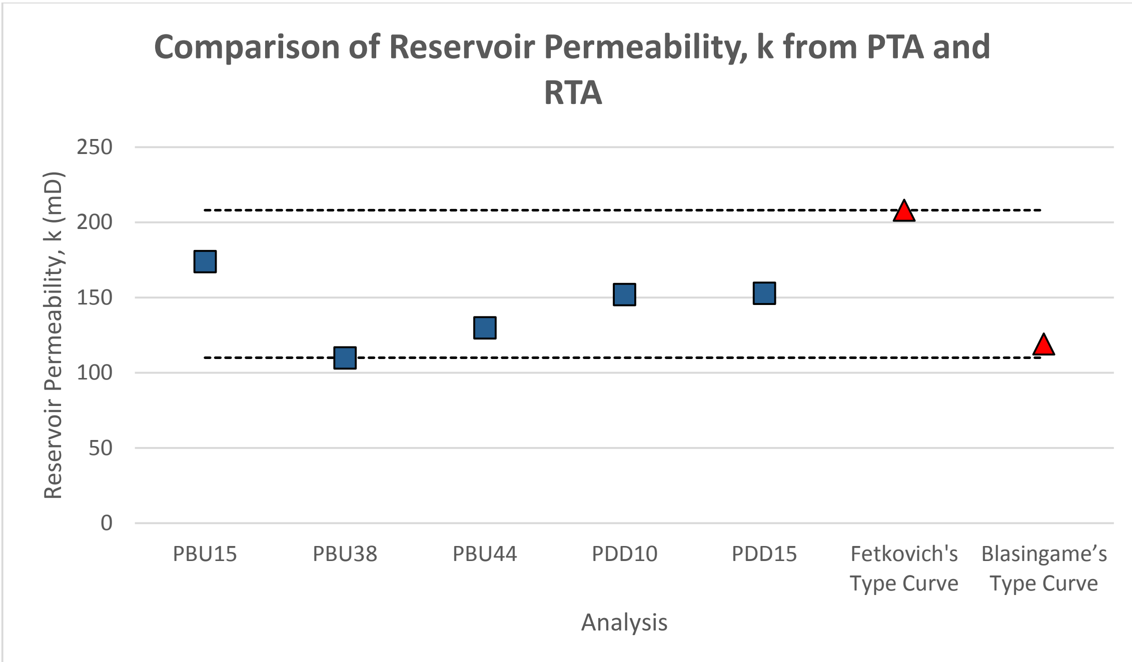


Figure 4.20: Comparison of Reservoir Permeability, k from Pressure Transient Analysis (PTA) and Rate Transient Analysis (RTA)

Figure 4.20 shows the comparison of reservoir permeability, k estimated from the five PTAs, Fetkovich's Type Curve Analysis and Blasingame's Type Curve Analysis. The comparison of permeability between all the seven analysis have the same trend as the comparison of well deliverability in Figure 4.19. This is because well deliverability is an expression describing the multiplication of reservoir permeability (k) with well production interval (h), which the latter is a constant for this study. The results show that the reservoir permeability estimated from all of the seven analysis fall in the range of 110 mD to 208 mD, which is the within the range of permeability for good reservoir (100 mD to 1000mD).

Although there is a difference of approximately 100 mD between the lowest and the highest permeability estimated from the PTAs and RTAs, this difference is considered to be small as the estimation of permeability itself consists of high uncertainties. Moreover, when comparing the average permeability obtained from PTA (143.8 mD) and the average permeability obtained from RTA (163.5 mD), the percentage difference is only 14%. Hence, it can be concluded that the permeability estimated by both PTA and RTA are reasonably close with each other.

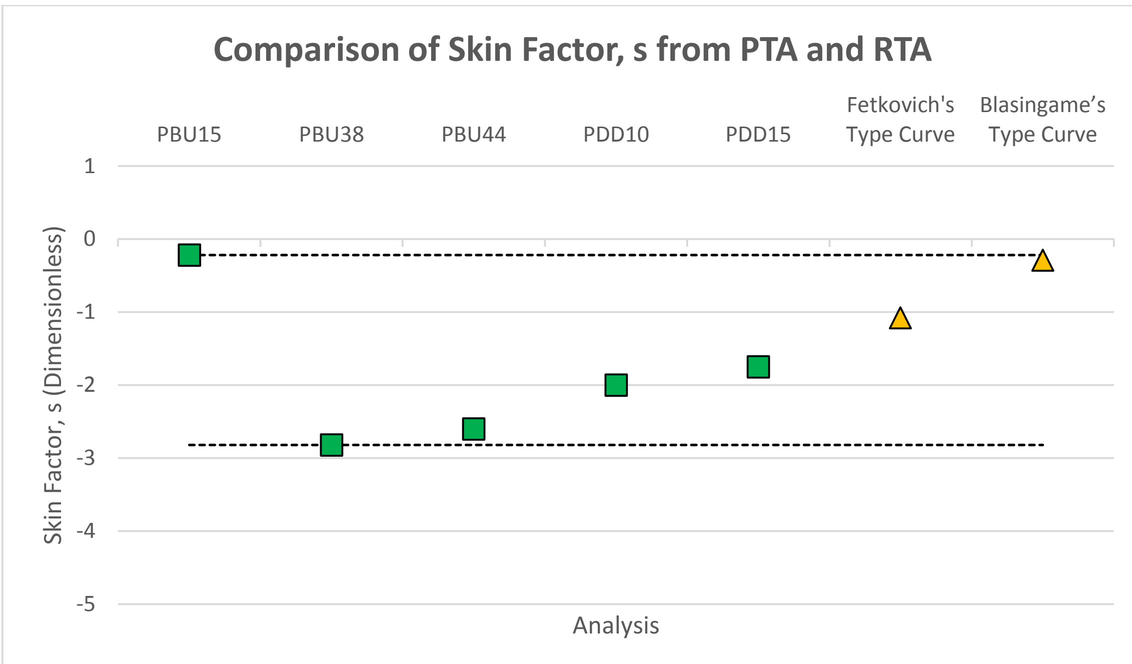


Figure 4.21: Comparison of Skin Factor,s from Pressure Transient Analysis (PTA) and Rate Transient Analysis (RTA)

Figure 4.21 shows the comparison of skin factor, s estimated from the five PTAs, Fetkovich's Type Curve Analysis and Blasingame's Type Curve Analysis. It can be clearly shown that all of the seven analysis estimated that Well A has low skin factor, which is in the range of -0.219 to -2.82. When comparing the average skin factor obtained from PTA (s= -1.88) and RTA (s= -0.69), it can be clearly shown that the difference are very small. It can thus be concluded that the skin factor estimated by both PTA and RTA method are reasonably close with each other.

4.2 Discussion

4.2.1 Reliability of Analysis Results

The data provided for this case study of Well A was only the pressure and production history of the well. The data provided did not indicated if there is a purposely designed PTA for Well A. Hence, the data used for pressure transient analysis are chosen such that the Well A had been producing/shut-in for sufficiently long period for the pressure response to stabilize before the test. This screening was done in order to filter those PBU or PDD that did not fulfill the basic assumptions of PTA and hence would result in unreliable result.

RTA on the other hand could only be applied only when there is natural decline in the production rate of the well. Hence, the production data was screened to identify the period where Well A experience the most obvious decline in its production rate. The well choke size associate with the production data was also checked to ensure that the decline in production was not due to the decrease in well choke size.

4.2.2 Limitation of Each Method

Both PTA and RTA have their own limitations and assumptions in analysis. PTA involves the analysis of pressure data of few hours or days, while RTA involve the analysis of production rate data of few months or years. Hence, PTA could give information about the reservoir properties at a particular time, while RTA could only give an average information of the reservoir properties over a certain period of time.

4.2.3 Source of Errors

The main source of error was the quality of the data itself. The data used for PTA in this case studies was only production and pressure history of the well. These data are not specially design for well testing purpose. Hence, a lot of fluctuation/noise can be observed in the data during analysis.

Error may also occur while filtering the data. It should also be noted that both the production data and pressure data were provided in different time scale: production data in day scale, while pressure data in minutes or hours. Therefore, the details that could be captured by these data may be different. For example, the production rate would show an average flow rate of the day instead of zero if the shut-in period is shorter than a day. Due to this reason, data filtering need to be carried out.

Human error can also be a source of error for this case studies. In this project, PTA and RTA were performed manually using ECRIN software. Analysis results would be different for different analyst.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

This chapter presents the conclusions that were drawn and some recommendations for future improvement of this project.

5.1 Conclusion

i) Both Rate Transient Analysis and Pressure Transient Analysis yield reasonably close estimation of reservoir parameters. For Well A, PTA analysis estimates that the average permeability and skin of the reservoir is 143.8 mD and -1.88 respectively, while RTA estimate that the average reservoir permeability and skin is 163.5 mD and -0.69 respectively. In term of average permeability, the difference between the results from both methods is only 14%, while in term of average skin factor, the difference in results is approximately ±1.

ii) Rate Transient Analysis can be a reliable substitute for Pressure Transient Analysis, provided that the well has undergoes natural decline in its production rate. Well testing are applicable all the time with properly designed plan, while advanced decline curve analysis are applicable only when there are decline in the well flow rate. These two method should be used interchangeably, depending on the availability of the data and economic constraints.

5.2 Recommendation

Some recommendations for the improvement of this projects are:

i) Investigate the reservoir parameters of more than one well to see that if the results of this project is consistent.

ii) Investigate the reservoir parameters for different system of well, such as dual porosity well and fracture well.

iii) Verify the results with those obtained from independent sources, such as logs and core data.

CHAPTER 6: REFERENCES

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CHAPTER 6: APPENDICES

Appendix A: List of Equations

Diffusivity Equation

$\frac{1}{r}\frac{\delta p}{\delta r}+\frac{\delta^2 p}{\delta r^2}=\frac{\emptyset\mu c_t}{k}\frac{\delta p}{\delta t}$……………………………………...……………EQUATION 1

Pressure Draw-Down Analysis

$p_{wf}=p_i-162.6\frac{qB\mu}{kh}\left[\log(t)+\log\left(\frac{k}{\emptyset\mu c_t r_w{}^2}\right)-3.23+0.869s\right]$………...EQUATION 2

$k=162.6\frac{qB\mu}{mh}$……………………………………………………..… EQUATION 3

$s=1.151\left[\frac{(P_i-P_{1hr})}{m}-\log\left(\frac{k}{\emptyset\mu c_t r_w{}^2}\right)+3.23\right]$…………………………….. EQUATION 4

Horner's Analysis

$p_{ws}=p_i-162.6\frac{qB\mu}{kh}\log(\frac{t_p+\Delta t}{\Delta t})$……………………………….…….……EQUATION 5

$k=162.6\frac{qB\mu}{mh}$ ……………………………………………..……....……EQUATION 6

$s=1.151\left[\frac{(P_{1hr}-P_{wf})}{m}-\log\left(\frac{k}{\emptyset\mu c_t r_w{}^2}\right)+3.23\right]$…………….……...……EQUATION 7

Arps' Equation

$q_t=\frac{q_i}{(1+bD_it)^{\frac{1}{b}}}$……………………………………..……………...……EQUATION 8

Fetkovich Type Curve

$$q_D = \frac{141.3q(t)\mu\beta}{kh(p_i - p_{wf})} \quad \text{EQUATION 9}$$

$$t_D = \frac{0.00634kt}{\emptyset\mu c_t {r_w}^2} \quad \text{EQUATION 10}$$

$$k = \frac{141.2\mu\beta}{h(p_i - p_{wf})}\left[\ln\left(\frac{r_e}{r_{wa}}\right) - \frac{1}{2}\right]\left(\frac{q}{q_D}\right)_{MP} \quad \text{EQUATION 11}$$

$$A = \frac{5.615\beta}{\emptyset h c_t (p_i - p_{wf})}\left(\frac{q}{q_D}\right)_{MP}\left(\frac{t}{t_D}\right)_{MP} \quad \text{EQUATION 12}$$

$$r_{wa} = \frac{r_e}{R_{eD}} \quad \text{EQUATION 13}$$

$$s = \ln\frac{r_w}{r_{wa}} \quad \text{EQUATION 14}$$

Blasingame Type Curve

$$(t_a)_{Dd} = \left(\frac{m}{b_{pss}}\right) t_a \quad \text{EQUATION 15}$$

$$m = \frac{1}{Gc_{ti}} \quad \text{EQUATION 16}$$

$$b_{pss} = \frac{70.6\mu_{gi}B_{gi}}{k_g h}\left[\ln\left(\frac{4A}{1.781C_A {r_{wa}}^2}\right)\right] \quad \text{EQUATION 17}$$

$$q_{Dd} = \left[\frac{q_g}{\bar{m}(p_i) - \bar{m}(p_{wf})}\right] b_{pss} \quad \text{EQUATION 18}$$

$$(q_{Dd})_i = \frac{1}{t_a}\int_0^{ta}\left(\frac{q_g}{\bar{m}(p_i) - \bar{m}(p_{wf})}\right) dt_a \quad \text{EQUATION 19}$$

$$(q_{Dd})_{id} = \left(\frac{-1}{t_a}\right)\frac{d}{dt_a}\left[\frac{1}{t_a}\int_0^{ta}\left(\frac{q_g}{\bar{m}(p_i) - \bar{m}(p_{wf})}\right) dt_a\right] \quad \text{EQUATION 20}$$

$$G = \frac{1}{c_{ti}}\left[\frac{t_a}{t_{Dd}}\right]_{MP}\left[\frac{(q_{Dd})_i}{q_{Dd}}\right]_{MP} \quad \text{EQUATION 21}$$

$$A = \frac{5.615 G B_{gi}}{h \emptyset (1 - S_{wi})} \quad \text{EQUATION 22}$$

$$r_e = \sqrt{\frac{A}{\pi}} \quad \text{EQUATION 23}$$

$$r_{wa} = \frac{r_e}{r_{eD}} \quad \text{EQUATION 24}$$

$$s = -\ln\left(\frac{r_{wa}}{r_w}\right) \quad \text{EQUATION 25}$$

$$k = \frac{141.2 B_{gi} \mu_{gi}}{h}\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2}\right]\left[\frac{(q_{Dd})_i}{q_{Dd}}\right]_{MP} \quad \text{EQUATION 26}$$

Appendix B: Plots for Pressure Transient Analysis

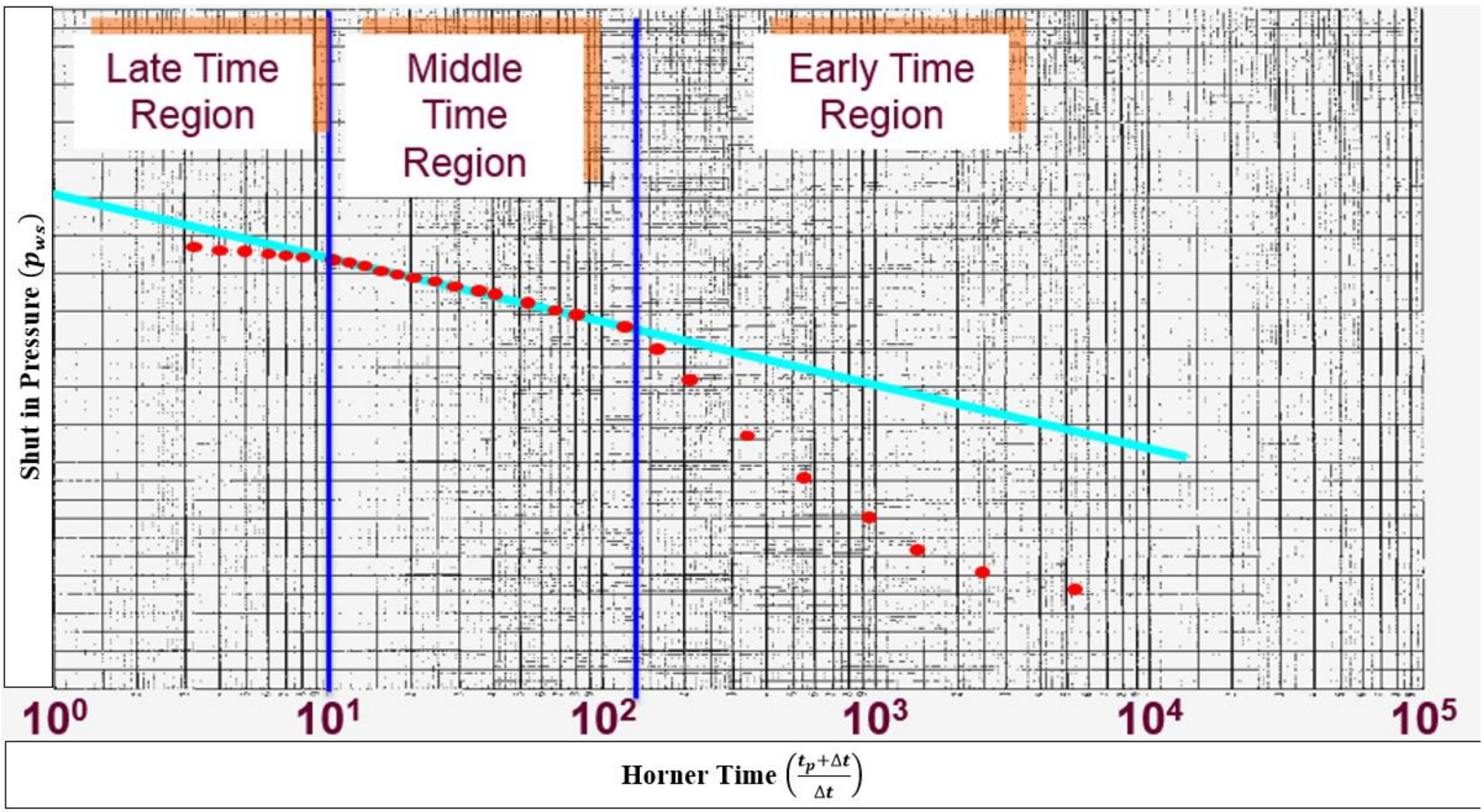

Figure 2.1: Horner's Plot

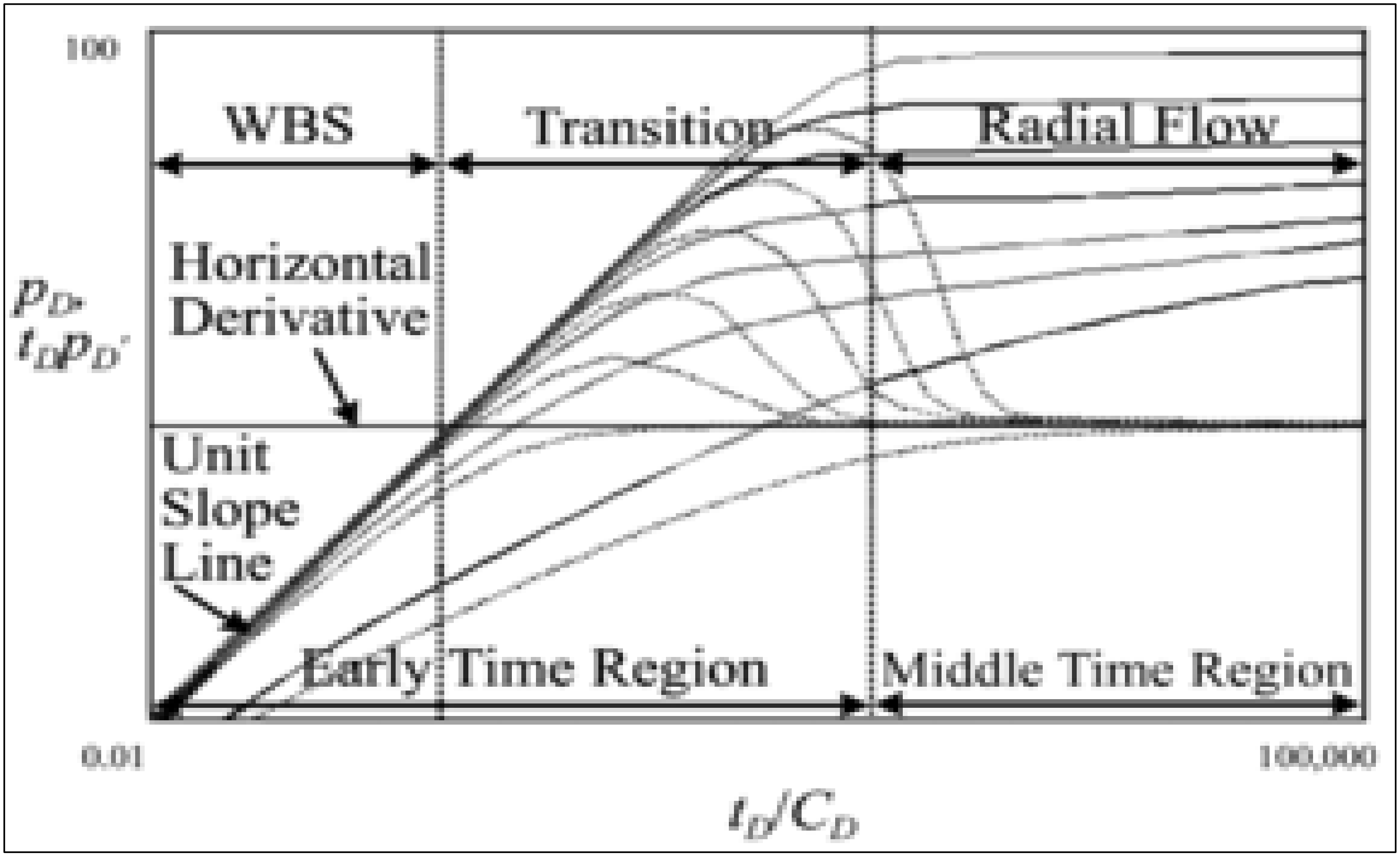

Figure 2.2: Bourdet-Gringarten Type Curve

Appendix C: Plots for Rate Transient Analysis

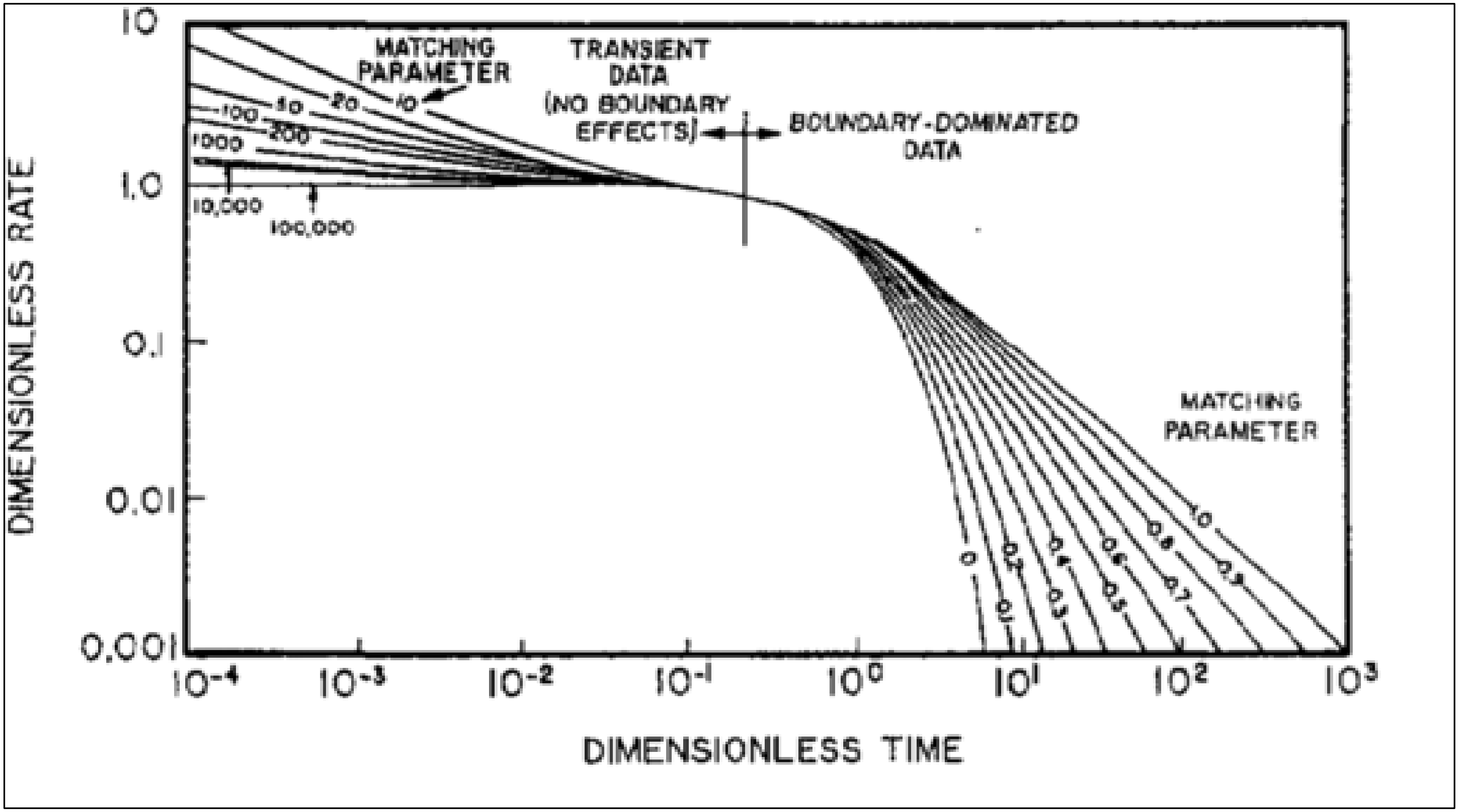

Figure 3.1: Fetkovich Type Curve

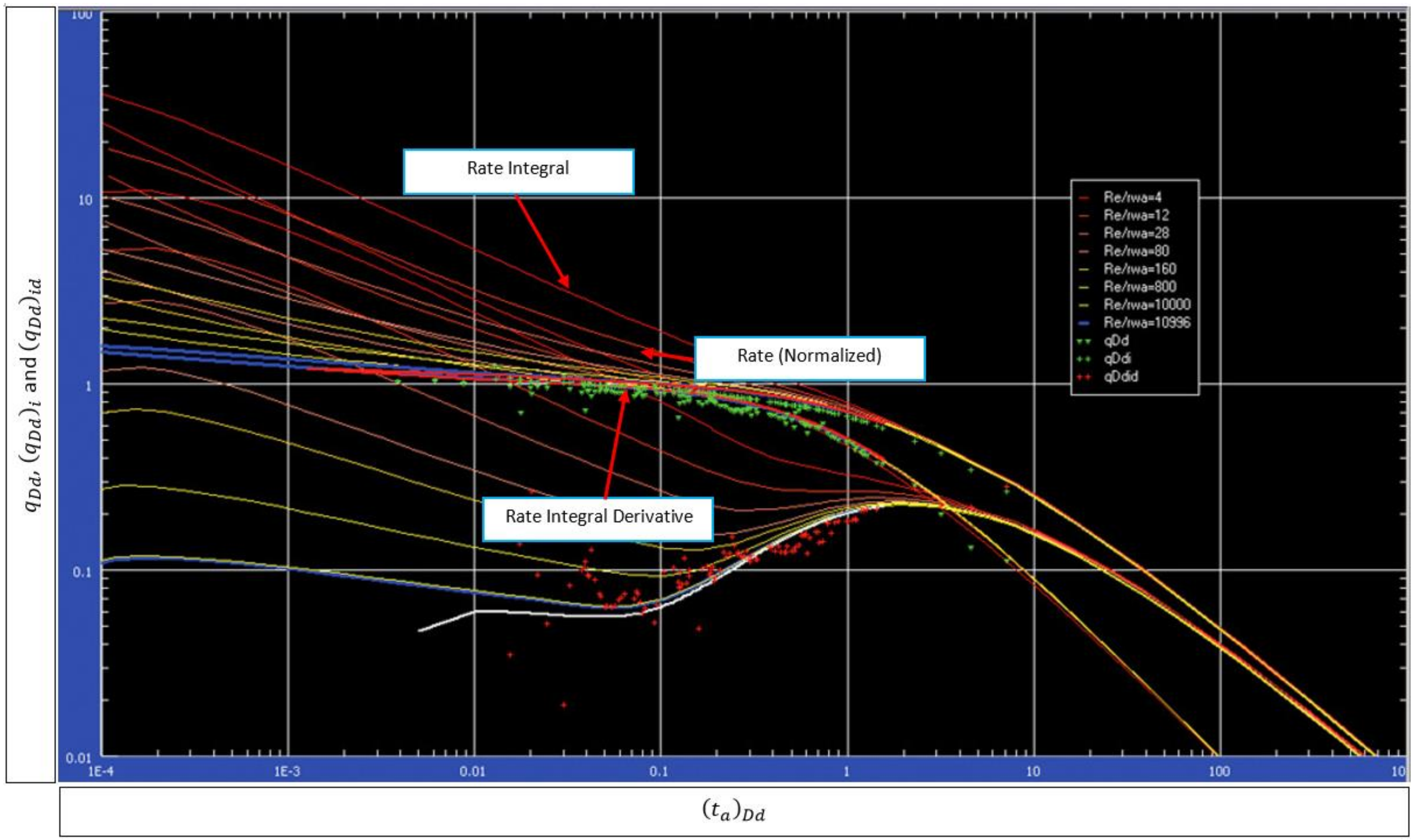

Figure 3.2: Blasingame Type Curve